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Evaluation of Pasture Systems and Grain Levels for Growing Beef Cattle with Prediction Equations for Estimating Animal Performance

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EVALUATION OF PASTURE SYSTEMS AND GRAIN LEVELS FOR GROWING BEEF CATTLE WITH PREDICTION EQUATIONS FOR ESTIMATING ANIMAL PERFORMANCE

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Doctor of Philosophy, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Advisor | Date

Date

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EVALUATION OF PASTURE SYSTEMS AND GRAIN LEVELS FOR GROWING BEEF CATTLE WITH PREDICTION EQUATIONS FOR ESTIMATING ANIMAL PERFORMANCE

Abstract

Steven C. Fransen

Under the supervision of Dr. F. R. Vigil

A three-year grazing study evaluated native, native-interseeded range and a tame grass pasture series for pasture production, quality and animal performance. Animal production and performance were evaluated with yearling steers fed corn daily at zero, 0.5 and 1.0 percent of body weight. Interseeding alfalfa into native rangelands enhanced sod-forming over bunch grasses and allowed alfalfa to become the dominant species. Alfalfa was not selectively grazed in the interseeded range and in 1978 contributed 35 percent of the dry matter yield during the spring and summer. Forage quality declined with maturity; IVDMD and CP decreased while ADF, NDF, lignin and silica all increased with the grazing season. Alfalfa greatly increased forage quality in the interseeded range with tame pastures having the best quality season-long. Five methods were evaluated to estimate dry matter intake of grazing steers. Methods using forage quality along with animal weights and gains gave higher predictions than using body weight alone. Average daily gains of steers increased with increasing levels of grain supplementation; however, no differences were found between pasture systems. Interseeded and tame pastures increased gains per ha and carrying capacity by 60 and 54 percent, respectively, over the native range. Grain supplementation at 0.5 and 1.0 percent of body weight increased carrying capacity by 9 and 21 percent, respectively over the zero grain level. Native and interseeded range steers consistently suffered weight loss in the late fall grazing periods at zero and 0.5 percent grain levels, while the 1.0 percent grain level allowed animals to maintain body weights. Native range required 32 percent more acreage per animal unit than interseeded or tame pastures. Four equations to predict mean average daily gain were recommended on the basis of research or producer use. Coefficients of determination ranged from 48.8 to 52.6 percent and standard deviations from 0.281 to 0.291. The most practical equations require estimates of dry matter intake, IVDMD (or TDN) ADF, NDF, animal body weight and period of the grazing season.

TABLE OF CONTENTS

Page

INTRODUCTION 1

LITERATURE REVIEW 12

I. Rangelands and Their Importance in the Great Plains . . 12

II. Modifications For Improving Pasture Quality, Yield and Performance 18

III. Basic Principles of Grazing Management and Pasture Utilization 21

Environmental Factors Affecting Plant Growth . . . 22
Plant Growth in Pastures 26
Plants Resistance to Grazing 29
Grazing Behavior of Livestock 30
Plant Regrowth After Grazing 33
Grazing Pressure 35
Grazing Systems 36

IV. Perspectives on Forage Quality Importance 41

Historical View 41
Forage Quality From The Plant's Viewpoint 45
Forage Quality From An Animal's Viewpoint 51

MATERIALS AND METHODS 63

Grazing Phase 63
Vegetation Sampling 65
Forage Quality Determinations 67
Estimations of Dry Matter Intake 68
Prediction of Mean Average Daily Gain 70
Prediction of Animal Performance on Pasture 71
Climatic Data 72

RESULTS AND DISCUSSION 73

I. Botanical Composition of Native and Interseeded Ranges . 73
II. Available Forage Dry Matter 75
III. Forage Quality Comparisons 77
IV. Estimations of Dry Matter Intake by Grazing Steers . . . 89
V. Performance of Grazing Steers on Pasture 98

Animal Performance on Pasture 98
Animal Gains Per Ha and Carrying Capacity 102
Production of Tame Series Components 104
Grain Efficiency 109
Ha Required Per Animal Unit 110

VI. Prediction of Mean Average Animal Daily Gain on Pasture 111

SUMMARY AND CONCLUSIONS 116

LITERATURE CITED 119

APPENDIX 142

LIST OF TABLES

Page

Table 1. Sampling dates of forage and animal weight dates by pasture period for native range and native interseeded ranges, 1978-1979 64

Table 2. Sampling dates of forage and animal weight dates by pasture period for tame pasture series, 1978-1979 . . 65

Table 3. Percent relative density and frequency of major plant species in native and interseeded ranges, 1978 74

Table 4. Available forage kg/ha and percent relative forage availability of pasture systems at early, mid and end of grazing system, 1978-1979 76

Table 5. Percent IVDMD of native, interseeded and interseeded range without the alfalfa component, short-season, 1978-1979 78

Table 6. Percent IVDMD of native and interseeded ranges, long-season, 1978-1979 79

Table 7. Percent ADF of native, interseeded and interseeded range without the alfalfa component, short-season, 1978-1979 79

Table 8. Percent ADF of native and interseeded ranges, long-season 1978-1979 80

Table 9. Percent NDF of native, interseeded and interseeded range without the alfalfa component, short-season, 1978-1979 81

Table 10. Percent NDF of native and interseeded ranges, long-season, 1978-1979 81

Table 11. Percent CP of native, interseeded and interseeded range without the alfalfa component, short-season, 1978-1979 82

Table 12. Percent CP of native and interseeded ranges, long-season, 1978-1979 83

Page

Table 13. Percent lignin of native, interseeded and interseeded range without the alfalfa component, 1978-1979 . . . 84

Table 14. Percent Lignin of native and interseeded ranges, season-long, 1978-1979 84

Table 15. Percent silica of native, interseeded and interseeded range without the alfalfa component, short-season, 1978-1979 85

Table 16. Percent silica of native and interseeded ranges, long-season, 1978-1979 85

Table 17. Forage quality of different pasture components of a tame pasture series during the 1978 and 1979 grazing season. Quality determinants in percent are IVDMD, ADF, NDF, CP, lignin and silica, 1978-1979 88

Table 18. Estimated dry matter intake, kg/day, for three pasture systems and five pasture periods. Based on Van Soest (1971) Method 1 90

Table 19. Estimated dry matter intake, kg/day, for three pasture systems, three grain levels, five pasture periods in 1978 and 1979. Based on Van Soest (1973b) Method 2 91

Table 20. Estimated dry matter intakes, kg/day, for three pasture systems, five pasture periods in 1978 and 1979. Based on Colburn and Evans (1968) Method 3A 93

Table 21. Estimated dry matter intake, kg/day for three grain levels and five pasture periods in 1978 and 1979. Based on Colburn and Evans (1968) Method 3A 93

Table 22. Estimated dry matter intake, kg/day, for three pasture systems at three grain levels and five pasture periods. Based on Colburn and Evans (1968) Method 3A 94

Table 23. Estimated dry matter intake, kg/day, for three pasture systems at five pasture periods. Based on Colburn and Evans (1968) Method 3B 95

Table 24. Estimated dry matter intake, kg/day, for three pasture systems at three grain levels. Based on Colburn and Evans (1968) Method 3B 95

Page

Table 25. Estimated dry matter intake, kg/day, for three pasture systems at three grain levels and five pasture periods. Based on Colburn and Evans (1968) Method 3B 96

Table 26. Estimated dry matter intake, kg/day, for three pasture systems, five pasture periods in 1978 and 1979. Based on Rohweder (1981) Method 4 97

Table 27. Estimated matter intake kg/day, for three grain levels at five pasture periods in 1978 and 1979. Based on Rohweder (1981) Method 4 97

Table 28. Average daily gain, kg, of steers with three levels of supplemental grain, 1977-1979 grazing seasons . . 100

Table 29. Average daily gain, kg, of steers on three pasture systems and three grain levels, 1977-1979 grazing season 100

Table 30. Average daily gain, kg, of steers on three pasture systems season-long and three grain levels season-long for 1977-1979 101

Table 31. Average daily gain, kg, of steers of three pasture systems and three grain levels through the grazing season, 1977-1979 101

Table 32. Total animal gains per ha, kg, of three pasture systems by years and three grain levels by years, 1977-1979 grazing season 103

Table 33. Carrying capacity, AUM/ha for three pasture systems and three grain levels, 1977-1979 103

Table 34. Carrying capacity, AUM/ha of three pasture systems, grain levels for the 1977-1979 grazing season 103

Table 35. Production of the different pasture components of a tame pasture series under three grain levels during the 1977, 1978 and 1979 grazing seasons 105

Table 36. Production of the different pasture components of a tame pasture series under three grain levels during the 1977 grazing season 106

Table 37. Production of the different pasture components of a tame pasture series under three grain levels during the 1978 grazing season 107

Page

Table 38. Production of the different pasture components of a tame pasture series under three grain levels during the 1979 grazing season 108

Table 39. Grain efficiency for improving total animal gains, kg, for three pasture systems and three grain levels, 1977-1979 109

Table 40. Approximate number of ha required to carry an animal unit for the entire grazing season by pasture system and grain level, 1977-1979 110

Table 41. Regression Equations for predicting mean steer ADG in pastures from estimates of forage dry matter intake, laboratory analysis, animal weights and grazing periods 114

INTRODUCTION

Through the use of the fossil records, scientists have developed a geologic time scale. This scale approximates ages of times when major events possibly occurred in the past. During the Mesozic Era, about 65 to 250 million years ago, dinosaurs and large toothed birds, giant gymnosperms and seed ferns were in great abundance. The Mesozic Era is divided into three periods; the Cretaceous Period (65 to 144 million years ago) terminated this Era. During the Cretaceous Period the Rocky, Andes, Alps and Himalaya Mountains were formed. The mountains slowly initiated climatic changes from a humid-tropical to a slightly cooler, semi-arid climate. The climatic change caused the extinction of the large dinosaurs and giant plant species, which became the basis of the Cenzoic Era. The Cenzoic Era, believed to have spanned from 2 to 65 million years ago, is divided into two Periods; the Tertiary and Quaternary. The Tertiary Period is further subdivided into five Epoch or Series. These Epoch are: Paleocene, Eocene, Oligocene, Miocene and Pliocene with approximate dates of 58 to 65, 36 to 58, 22 to 36, 5 to 22, and 2 to 6 million years ago, respectively. The Quaternary Period is subdivided into two Epoch: the Recent or Holocene (present to about one million years ago) and Pleistocene (one to two million years ago) (Flint and Skinner 1977).

In North America, four glacial advances and retreats have occurred during the Quaternary Period; the Nebraskan, Kansan, Illinoian and Wisconsin. The Wisconsin is the most recent, retreating between 10 and 50 thousand years ago (Boellstroff 1978).

The coevolution of grasses and grass-like plants with grazing herbivores spans most of the Tertiary and Quaternary Periods. The following discussion is a synthesis of the fossil record on the coevolution as reviewed by Stebbins (1981) and Janis (1976). Fortunately, teeth and hoofs, pollen, and leaf epidermis have been fossilized for most time periods and these give the best clues as to how this coevolution proceeded. During the Paleocene and Eocene Epoch's, two groups of primitive ungulates appeared; these were the perissodactyls and artiodactyls. Modern day survivors of the perissodactyls are the horse (*Equus caballus*) and rhinoceros (*Rhinoceros* spp.). Artiodactyl survivors include the pig (*Sus serofa*), camel (*Camelus* spp.), deer (*Odocaileus* spp.), giraffe (*Giraffa* spp.), antelope (*Antilocapra* spp.), cattle (*Bos taurus*), and sheep (*Ovis aries*). Plant life during the late Cretaceous Period and early Paleocene Epoch, was very succulent; plants produced many fruits or berries and had highly palatable leaves. Fruits were high in protein and other nutrients and low in fiber.

One of the first ungulates to emerge was the primitive horse; it was of short-stature, had low-crowned teeth that lacked an enamel covering. These animals developed a sac-like fermentation chamber between the small and large intestines called the cecum, that allowed for some digestion of fibrous material. The cecum provided for limited fermentation as the diet of succulent fruits and leaves needed little or no fermentation. Microorganisms found the warm environment and nearly neutral pH of the cecum quite favorable. The population of perissodactyls climaxed during the Paleocene Epoch when another group of ungulates increased in numbers. The artiodactyls appeared in the late Paleocene and increased rapidly during the Eocene Epoch. The Eocene Epoch climate was somewhat cooler and drier than the Paleocene. Fossilized plant leaf epidermis found in Germany shows that at least the Oryzeae family was well differentiated during the Eocene Epoch. Opaline silica particles impregnated in the cell walls of these grasses aided in their identification. The increase fiber content and silica particles of grasses may be the major reason ungulates began to develop higher crowned teeth with more enamel and a second type of fermentation digestion. The artiodactyls developed a multiple stomach complex with the rumen-reticulum as the largest and first of the stomachs. It has been theorized that the large fermentation chamber of these animals is in response to a more fibrous diet. Microorganims found a favorable environment in the rumen-reticulum and this allowed for the development of a symbiotic relationship between the animals and microorganisms.

During the Eocene Epoch continents were much closer together allowing for large amounts of plant and animal material to be exchanged between North America and Eurasia, and South America and Africa. Records indicate that no exchanges were made between North and South America until later. The North American continent was covered by a continuous forest, whereas South America was beginning to develop some savannas. The opening of the forest allowed for the migration of grasses into these areas, forming savannas; this, along with grass material exchanged between South America and Africa, appears to have been the correct environmental stimulus that allowed the coevolution of grasses and grazing ungulates to begin.

The Oligocene Epoch climate was cooler and drier than the Eocene Epoch. Plants were slowly changing in response to the climate by developing more fiber and becoming less digestible. The ungulates responsed by increasing their body size, since we now know that body maintenance decreases with an increase in body size (Kleiber 1961). An increased body size allowed animals to increase their food intake to sustain a nutrient level previously enjoyed. The rumen of the artiodactyls allowed the animals to graze large amounts of feed at one time. Then, within the protection of others, they could ruminate, rechew the food into smaller particle sizes to enhance digestion. This has been considered a defense mechanism and is commonly referred to as the "eat and run" theory. Grasses from the Stipeae and Phalarideae tribes, both genera Stipa and Phalaris, came into greater importance and probably reached North America from Eurasia during the Oligoecene Epoch. The record suggests that North America contained an abundance of Stipeae grasses during the Miocene Epoch, but these grasses and the native horse and camel did not migrate into South America until the Pliocene Epoch. The Stipeae grasses likely contained more silica and fiber than the other grasses present, thereby forcing the ungulates to increase their daily food intake. The increased food intake probably substituted for the lower quality diet and resulted in about the same nutrient level within the animal. In the artiodactyls, intake could not only be increased to a point then reduced, but the food particulates remained in the digestive system longer. In the perissodactyls, however, significant decreases in food intake were not found when forage quality was poor enough to decrease intake in artiodactyls. The perissodactyls compensated by increasing their food intake to higher levels, resulting in a relatively rapid rate of passage, but a sustained nutrient intake. Thus, the hypothesis has been proposed that under limited dry matter quantity the artiodactyls maintain the advantage, but under low forage quality the perissodactyls have the edge. The Stipoid grasses have then played an enormous role in changing the size of the ungulates as well as their teeth.

Marshall et al. (1982) discuss the "Great American Interchange" of mammals. Actually, two interchanges took place, the one already described and a second during the Pliocene and Pleistocene Epoch's. The first migration between North and South America occurred by either island hopping or through the emergence of a land bridge. The second migration took place via the Panamanian land bridge. Although the total number of animal families on both continents is balanced, they found that more North American genera migrated to South America rather than the reverse. Because of the great climatic changes taking place on the North American continent, both plant and animal species appear to be more diversified. The South American climate was relatively mild for long periods of time and the biotic habitat does not seem to be as diversified, thus their contribution to North America was kept at a minimum. Unfortunately, the fossilized plant record during this time is not available.

Development of the native grasslands in North America, and more specifically of the Midwest (Gleason 1923) and South Dakota (Harvey

1908), have been reviewed. North America has seen the advance and retreat of four glacial periods. With the Kansan and Wisconsin having the major influences on the Great Plains plant habitat. Migration of plants was closely related to the advancement and retreat of the glaciers. Plant migrations have resulted in an intermixing of cool and warm season grasses, forbes and browse plant species. Grazing animals must also be included as a factor in the development of the native grasslands. Often times range and forage scientists discuss the destructive effects of overgrazing on the range resources. Buffalo (Bison bison) were the major ungulate present on the prairies during their development and it can be hypothesized that the buffalo played a positive role in the development of rangelands through grazing rather than overgrazing. Edward (1978) used surveys and observation on the habits of buffalo grazing in grass and forest-grasslands. He found that buffalo in forest-grasslands may have been the major force in reducing forest competition. Through the use of horning and rubbing on trees, buffalo may gridle more than 75 percent of the trees in a pasture in one year. Buffalo also trample a large amount of understory vegetation and this appears to have been more severe in the West than in the Midwest. When buffalo were given the opportunity to graze an alfalfa-grass pasture, they ate the grass and virtually did not make use of the alfalfa. When comparing pastures that had been grazed by cattle to those grazed by buffalo, forbes were completely grazed out by cattle but were still in abundance in buffalo pastures. Edwards (1978) concludes that "over thousands of years, buffalo, plus elk, must have had a tremendous botanical impact, not only by their continuous feeding, thrashing, trampling, and tearing of vegetation, but also by their selective use of vegetation and seasonal variations in grazing."

Ellison (1960) reviewed the influence of grazing on the development of rangelands. He viewed grazing primarily as a secondary succession because man and his management played no role in the original vegetation development. He concluded that grazing animals provided various benefits to the existing vegetation:

1. Grazing may stimulate herbage production--this influence may be long lasting in browse and shrub species, but only short stimulating in for grasses.

2. Plants may endure drought better due to a reduced leaf area from the grazing process.

3. By reducing some of the herbage, less mulch may accumulate on the soil surface and encourage spring growth and increased yield.

4. Grazing animals can carry seed of forage plants, transporting them from one area to another. They also trample forage and soil, burying seeds.

5. Dung and decomposition of bodies may aid in fertilizing the range.

Researchers have theorized that the saliva of grazing ungulates may have aided in the coevolution of grasses and animals. Viewing the grazing process as being beneficial rather than detrimental, Reardon et al. (1972) found bovine saliva and thiamine to increase forage and root dry matter yields of 232 and 398 percent, respectively, over nontreated clipped sideoats grama (Bouteloua cuntipendula) plants. Bonner and Greene (1939) studied the influence of thiamine applied to four grasses growing in sand. After a six week period they found a 160 to 453 percent increase in top dry weight. Only two grasses were tested for changes in root dry matter weight; they found a 137 and 197 percent increase for the thiamine treated grasses. The effects of added thiamine were evident for seedling as well as established plants. Reardon et al. (1974) applied bovine saliva and thiamine to sideoats grama clipped at different intensities and heights. Sideoats grama cut at 15 cm every six weeks had a 40, 42 and 23 percent increase in dry matter yield over the control when thiamine was applied on the plant, added to the soil, or saliva applied to the plant, respectively. Adding thiamine or saliva did not increase grass yields when clipped to 7.6 cm heights. Reardon et al. (1978), establishing sideoats grama seedlings, found large yield responses to saliva and thiamine from seedlings grown in sand or low fertility soils, but not in seedlings grown under adequate fertility. From these studies it appears that thiamine at concentrations similar to those found in bovine saliva (about 10 parts per billion) and bovine saliva, collected from the mouth, often stimulate seedling growth, forage and root yields of established perennial grasses.

Johnston and Bailey (1972) collected bovine saliva from the rumen and compared it to water applications on two Festuca species.

Grasses were clipped to various heights every four weeks in the greenhouse. They found no differences between water and saliva on dry matter yield and tiller numbers. Detling et al. (1980) collected bison saliva from an esophageal fistual, applied it to bluegrama plants, then measured changes in net photosynthesis, respiration rate, and distribution of ^{14}C for a ten day period after clipping. They found no differences between the saliva and control. The lack of yield responses may have been due to their sampling technique (Johnston and Bailey 1972) or testing for a limited time period (Detling et al. 1980). The lack of response could have also been due to the fact that saliva taken from the mouth may differ from that of the esophageal and rumen.

Scattered throughout the Plant Kingdom are chemical compounds referred to as secondary metabolites. These compounds are found in, but not limited to, the Leguminoseae (Smoleski et al. 1981), Crucifereae (Feeny 1977) and Gramineae (Marten et al. 1973, Marten et al. 1976) families. Secondary metabolites are generally considered as non-essential products of cellular metabolism but they have been implicated as defense mechanisms against grazing herbivores (Levin 1976, Smily 1978, McNaughton 1978, Carroll and Hoffman 1980, Sik 1980, Smolenski et al. 1981). These metabolites act as a deterrant and thus an ecological defense mechanism to grazing animals. Most of the research has been conducted with insect herbivores with only a few studies with large ungulates. Two studies with large ungulates, such as African buffalo (Syncerus caffer), wildebeest (Connochates taurenies albojubatus), zebra (Equus burchelli), Thompson's gazelle (Gazella thomsonii) (McNaughton 1978) and beef cattle (Atsatt and O'Dowd 1976), have been reported. In both studies known, palatable grasses were grown in association with less palatable plants. Atsatt and O'Dowd (1976) found a linear, positive relationship between increased amounts of grasses grazed and decreased cover (percentage remaining) of unpalatable plants. McNaughton (1978) found that palatable plants were not grazed by either the African buffalo or the wildebeest, but were grazed by zebra and Thompson's gazelle. He concludes that the more selective grazing ungulates, zebra and gazelle, will graze the palatable grasses in the presence of unpalatable plants, but non-selective ungulates will not. The secondary metabolites in the plants may be toxic to the grazing animal. Janis (1976) postulates that another reason the ungulates needed to increase their body size was as plants were synthesizing more toxic secondary metabolites, a large body size was required as a dilution effect. Microorganism in the fermentation chambers also are thought to aid in the detoxification process of the secondary metabolites (Janis 1976).

The interdependence between soil-plant-animal is deeply rooted in past history. This interrelationship is the major factor for influencing gains per animal and land area. Because of the closeness of these variables, attempts to describe different factors that influence the outcome of pasture and animal responses have been limited and confined to only a few plant species. The objectives of this study were:

1. To evaluate production of native, native-interseeded range and tame pasture series by agronomic methods and grazing steers.

2. To evaluate the influence of supplemented energy in animal gains and carrying capacities.

3. To evaluate changes in forage quality during the grazing season.

4. To compare actual and predicted animal performance on pasture using different estimates of dry matter intake and forage digestibility.

LITERATURE REVIEW

I. Rangelands and Their Importance in the Great Plains

Rangelands are lands where the native vegetation is dominated by grasses, grass-like plants, forbes or shrubs suitable for grazing or browsing. This also includes lands that have been revegetated by natural or artificial means to provide a forage cover that can be managed like natural vegetation (Society of Range Management 1974). Bommer (1978) states "rangeland is terminology established in the United States, but is internationally understood as applying to grazing land derived from natural vegetation being under extensive use and of low productivity as compared to pasture or forage crops" (Bommer 1978).

Rangelands provide a wide variety of goods and services, rather than any particular use of the land. The majority of the world's meat, milk, wool, hides, and other animal products are derived from rangelands. Ranges also provide forage and habitat for wildlife, a natural germ plasm of undomesticated plant materials that could be used in future plant breeding programs, recharge underground aquifers, and are a source of great beauty for those who love the outdoors.

Of the total land area in the 50 states, 358 million ha or 39.2 percent is occupied by rangeland. In the 48 contiguous states, 263 million ha or 34.4 percent is range. Rangeland encompasses 55.8 percent of the land area of the 17 western states or 99 percent of the rangeland in the 48 contiguous states (USDA FS-345 1980). About 226 million ha or 86 percent of the rangeland in the lower 48 states is found in the Great Plains-Rocky Mountain region. Range and pasture land occupy about 58 percent of South Dakota's 19.8 million ha. About 3.2 and 8.3 million ha is found on the east and west sides of the Missouri River, respectively (Old West Regional Commission 1977).

The United States Department of Agriculture (USDA) has grouped similar potential vegetation types of the Great Plains into four predominant ecosystems (Garrison et al. 1977). The Great Plains extends from Canada to Mexico and from the Rocky Mountains to the deciduous forest (Wisconsin-Indiana). The vegetation of these ecosystems is described as follows:

Plains grasslands: Grasslands composed of predominately short, warm-season grasses with minor interspersion of forbs and shrubs. Buffalo grass (Buchloe dactyloides) and blue grama (Bouteloua gracilis) dominate the more western and drier areas. Where western wheatgrass (Agropyron smithii), green needle grass (Stipa viridula), and needle-and-thread (Stipa comata) are of medium stature and dominate on the eastern part of the ecosystem. Shrubs like juniper (Juniperus spp.) and sagebrush (Artemisia spp.), are found in the more northern regions. While mesquite (Prosopis juliflora) and rabbitbrush (Chrysothamnus spp.) favor the more southern region of these grasslands.

True prairie: Also known as the "tall-grass" or true prairie, the vegetation is dominated by bluestems (Andropogon spp.), indiangrass (Sorghastrum nutans), and switchgrass (Panicum virgatum). Willows (Salix spp.) and deciduous trees grown along the stream banks where they have been protected from many grassland fires.

Shinnery: This ecosystem is a midgrass prairie with open to dense stands of broad-leaved deciduous shrubs and some needle-leaved low trees. Little bluestem (Schizachyrium scoparium) and side oats grama are the major grasses with mesquite and Harvard oak (Quercus harvardii) as the major shrubs and yucca (Yucca spp.) as the major low shrub.

Texas savanna: The savanna ecosystem is more densely covered with shrubs, low growing trees and intermixed with evergreens. Mesquite is the dominant shrub along with junipers and oaks. Bluestems, buffalo grass, and gramas are the grasses dispersed among the shrubs.

The Plains and Prairie grassland ecosystems cover about 87.5 million ha or 74 percent of all grassland ecosystems in the lower 48 states. The two shrubland ecosystems, Shinnery and Texas savanna, cover about 13,427 ha or about 9.3 percent of all shrublands in the lower 48 states. The four ecosystems combined occupy about 101 million ha or about 38.4 percent of all the grass and shrubland ecosystem acres of the United States (USDA FS-345 1980).

Livestock grazing is the major use of Great Plains rangeland. Rangeland productivity is usually reported in terms of Animal Unit Months (AUM's). One AUM is the amount of forage required by a 1,000 pound cow, with or without calf, for one month. The Plains, Prairie, Shinnery and Texas savanna ecosystems carry about 118 million AUM's or about 62.1 percent of the AUM's for all the grass and shrubland ecosystems in the 48 contiguous states. The Plains and Prairie grassland ecosystems contribute 99.7 million AUM's or 84.5 percent of the total Great Plains AUM's.

The Forest Service (USDA FS-345 1980) subdivided range productivity into different levels of management. These levels are:

1. Some livestock: Livestock numbers are strictly controlled for the range capability of carrying livestock, but very little attempt is made to control the pattern of grazing and achieve a uniform livestock distribution. Investments are minimal and then only to maintain the integrity of the range during the grazing process.

2. Extensive management: Major emphasis is placed on full plant vigor and utilization of available forage by the livestock. Practices such as grazing systems and the installation of range improvements aid in realizing this goal. Cultural practices, such as reseeding and fertilization are not used.

3. Intensive management: Livestock production and utilization are maximized. Multiple use of the range while maintaining the range and surrounding environment is very important. Use of cost-efficient practices and technology can be used to improve livestock production and utilization.

4. Maximized livestock: While maintaining soil and water resources, livestock production is maximized. Range species may be replaced by improved tame forages and large economic investments are required for implementation of improvements, cultural practices, and animal husbandry. All practices must be cost-efficient and multiple use of resources is not a priority.

5. Exploitative grazing: The classical over-grazing of rangelands. Here no concern is given to multiple use, maintenance of

the basic soil, and water resources. Livestock numbers often exceed recommended levels causing reduced plant vigor and potential erosion.

The productivity of the Plains and Prairie ecosystems is about 99.7 million AUM's; some livestock, extensive management, intensive management, maximum livestock, and exploitative grazing, respectively, have 4.0, 40.0, 17.4, 22.9, and 15.4 million AUM's. The Shinnery and Texas savanna ecosystems contribute about 18.3 million AUM's of which 0.5, 1.9, 7.5, 1.6, and 6.8 million AUM's, respectively, are for some livestock, extensive management, intensive management, maximized livestock, and exploitative grazing, respectively.

Collectively, these data point out several important facts about the productivity and management of rangelands in the Great Plains; these are:

1. The greatest productivity of AUM's is from grassland ecosystems.

2. The extensive management (a relatively low management level) regime supports the greatest number of grassland AUM's.

3. The intensive management (a relatively high management level) regime supports the greatest number of shrubland AUM's.

4. Over 37 and 15 percent of the shrubland and grassland, respectively, have been exploitated by overgrazing.

What role will the rangelands play in meeting the increased demands of beef comsumption in the future? The Forest Range Task Force reported that nationwide rangelands produced about 215 million AUM's in 1970. These same lands will need to produce 320 and 394 million AUM's by 2000 and 2020, respectively. This represents a 49 and 83 percent increase of 1970 levels; can it be done? Mitchell (1976), Grelen (1978), Cook et al. (1981), and Pimental et al. (1980) believe rangelands can provide the beef demanded by consumers, but cattle will be sold at lighter weights than those fattened in drylot. These authors predict the majority of the increased production will come from the range-forest lands in the southeastern United States where annual precipitation is evenly distributed and a long season of grazing contribute for increasing AUM's. Inorganic nutrients only seem to be the limiting factor. Pimental et al. (1980) estimates that increases of 6 and 200 times the current levels of labor and energy, respectively, on these lands are needed to achieve these demands. If we do not have these inputs, along with increased range research, it might very well be that what Box (1974) predicted will come to pass: "red meat will be eaten only by those affluent few who can afford it."

II. Modifications For Improving Pasture Quality, Yield and Performance

Over the years, numerous practices have been evaluated to increase stocking rates of pastures and improve forage quality. Two such practices are pasture renovation (interseeding) and supplementation of stockers with energy and/or protein. From the producers point of view, maximum net return per unit land area is the major goal, which may or may not include maximum beef production. Before 1950, limited research was conducted on feeding grain on pasture or forage finishing. Feed grains were in abundance and the consumer demand for Choice beef was increasing. Feedlots were efficient and able to finish cattle in a relatively short period of time with a high-quality grain-fed product at a relatively low price, In the 1970's, energy costs resulted in higher cost of feed grains and increased animal gain cost; feeders started looking for larger animals coming off pasture to reduce the number of days required for finishing. The cow-calf man, realizing the feeders wanted larger cattle, searched for new methods of increased cattle size coming off pasture since less than optimum performance is often found with fattening cattle on pasture (Clanton 1977, Nelson and Landblom 1978, McCone 1951, Blaser et al. 1956, Roundtree et al. 1974).

Roughages, even high-quality pastures, are more bulky and generally have less energy than concentrates. When energy is supplemented to grazing cattle, two animal responses have been observed. Both are dependent on forage quality. These responses have been termed the additive and substitutive affect (Coleman 1977). With low-quality forages and low animal performance, supplemental energy provides additional energy intake with little affect on forage intake. The grain energy (NE) plus the forage energy are thus additive (Mott et al. 1968, Coleman 1977). With high-quality forages, increased levels of energy supplmented reduce the amount of dry matter intake as energy provided by the pasture; thus, a substitution of NE for forage energy results. Substitution may be expressed by differences in greater stocking rates or animal performance (Lake et al. 1974, Coleman et al. 1976, Perry et al. 1971, 1972, Mott et al. 1971, Burris et al. 1976, Embry 1973, 1976, Embry and Bush 1979, Schupp et al. 1979, Barrick et al. 1976). Embry and Bush (1979) were able to more than double the average daily gain of grazing steers on pasture with full fed as compared to the control with 50 percent less land available per animal. They noted that ample forage was available during the grazing season; thus, NE was supplying the major portion of the diet energy. Coleman (1977) has summarized the responses of feeding NE to cattle on pasture. These are:

1. Supplemental energy on pasture can result in increased average daily gains, stocking rates, or both.

2. Forage energy substitution by NE will be greater on high-quality rather than low-quality pasture.

3. Increasing the level of NE reduces its efficiency in converting GE to body weight gain.

4. Current prices of cattle and grain will often determine what feed and at what levels it can be fed to realize a profit.

Carcass quality and consumer acceptability of forage-fed beef are also important. Early research indicated that forage-fed beef tends to have yellow fat as compared to white fat with grain fed beef. The yellow fat is often associated with lower flavor, tenderness, dressing percentage, amount of desirable cuts, more odor and muscle discoloration (Wheeling et al. 1975, Meyer et al. 1960, Regean et al. 1976, Craig et al 1959, Harrison et al. 1978, Schroeder et al. 1980). Feeding limited levels of grain on pasture often greatly improves the muscle color, dressing percentage, shelflife, and consumer acceptability (Pate et al. 1976, Shinn et al. 1976, Bowling et al. 1977, 1978, Coleman et al. 1976, Hendrick et al. 1972, Burris et al. 1976).

Pasture renovation, like supplemental feeding of energy on pasture, has gradually increased in popularity since World War II. Renovation or interseeding is simply the seeding of a grass or legume into an existing low productive sod with a minimum of disturbance. Alfalfa is often the legume chosen for interseeding: however, other legumes may also be used (Posler and Fransen 1978). A review of interseeding is provided by Akundabweni (1980). Interseeding of a legume into a sod stand will often increase the productivity of the stand and the quality of the pasture. Often the soil nitrogen levels will be maintain with the legume component present, rather than being depleted as in a grass sward. Less soil moisture is lost with interseeding than the conventional seed bed, which makes this method flexible enough to establish legumes on steep hill sides. The addition of the legume should also increase animal performance on the interseeded pastures.

III. Basic Principles of Grazing Management and Pasture Utilization

The herdsman effectively utilized plants, animals, and the environment to provide himself with income and food for thousands of years. Nearly all herding was communal and often nomadic on lands generally considered wasteland, lands that could not be tilled or used to raise crops. Overgrazing was a common practice causing slow changes in vegetative habitat (Donald 1965). Spedding (1971) states "the herdsman presumably gave little attention to the conservation of his grazing resources or to their improvement, but the nomadic way of life does represent a form of large-scale, controlled, rotational grazing with at least some of the usual characteristics of these practices such as defoliation over limited periods alternating with long recovery periods for the plant population". Thus, it is possible to trace our modern day grazing practices and systems of management back to the herdsman and herding. About 300 or so years ago herding slowly evolved to grazing with the construction of hedge-type fences and a centralized location of watering. The herdsman had greater management of his livestock, but pastureland was still considered of low quality and untilled. Since the turn of the century attitudes toward pastureland and pasture plants have changed dramatically. Forages are now considered a "crop" rather than just plants that occupied space and regrow after grazing. Cultural practices have been devised for this group of crop plants as they have for most crops used directly for human food. Modern day grazing systems are appreciated more for what they can and cannot provide by understanding the morphological and physiological changes that occur within the plant canopy during the grazing process.

Environmental Factors Affecting Plant Growth

The plant species generally considered forage crops are in the grass (Gramineae) and the legume (Leguminoseae) families. In recent years, biochemists and physiologists have described two modes of carbon dioxide (CO_2) fixation in grasses. The Calvin cycle, or C_3 pathway, where 3-phosphoglyceric acid is the first stable product of photosynthesis (Calvin and Bassham 1962). The Hatch-Slack, or C_4 pathway has oxaloacetate, malate and aspartate as the first stable 4-carbon compounds (Hatch and Slack 1966). C_3 plants are of temperate origin and are usually characterized by having a low light saturation point, optimum temperature for growth of 20-25°C, high CO_2 compensation point, and photo-respiration. C_4 plants are of tropical or subtropical origin, having a high light saturation point, optimum growth of 30-40°C, low CO_2 compensation point, a Kranz-type leaf anatomy and no photorespiration (Bjorkman 1976). Differences of two to three times have been found in productivity of C_4 species over the C_3 under some conditions (Zelitch 1971). However, under favorable conditions, differences between the two CO_2 fixation pathways may be minimal (Gifford 1974).

Light, moisture and temperature are the cardinal environmental factors that affect photosynthetic rate of plants by reducing CO_2 fixation if one or more is limiting. In the discussion to follow, it is assumed that water is not limiting plant growth. Thus, the influence of light intensity and temperature on plant growth and regrowth after defoliation will be discussed.

Growth of the young grass seedling through tillering has been reviewed by several authors (Langer 1963, Humphries and Wheeler 1963; Jewiss 1966, Sachs 1965, Anslow 1966). Generally, the apical meristem within the coleoptile is actively dividing into primordia that give rise to leaf sheath and lamina. Many different stages of primordia development are present in the apical meristem. Within each axil of the leaf lies an axillary bud that is undergoing active cell division. This axillary bud is complete with apical meristem, leaves, nodes, internodes and adventitious roots. Under favorable environmental conditions the axillary buds develop into tillers. Tillers can be annual, biennial or perennial. Beaty et al. (1978b) showed switchgrass developed new tillers from rhizomes, and these tillers were found to be biennial in life span. The first year new axillary buds gave rise to slow growing rhizomes, covered with scale leaves and possibly roots. In the following year, rhizome tips begin verticle growth until the shoot emerges as a slightly elongated rosette of leaves. Internodes elongate with the lowest phytomer first and then progressively upward. Removal of the apical meristem will initiate axillary bud growth in leaf axils and from the crown. Tiller formation normally declines with stem elongation (Langer 1958), flowering (Langer 1963) and ovary formation (Mansot 1965).

Light intensity and temperature greatly influence the amount of plant tillering. Generally, high temperatures reduce tiller number and leaf width (Ryle 1964, Cooper and Tainton 1968), but increase the rate of leaf appearance, number of live leaves and leaf length (Ryle 1965).

Decreasing light intensity, as found under shading conditions in the plant canopy, decreased tiller number, leaf width and thickness, leaf emergence and expansion, but increases internode length and plant height (Langer 1963, Friend 1966, Ketellapper 1960, Ludlow et al. 1974). Tiller number is decreased because shading reduces rate of leaf appearance, providing for fewer axil sites from which tillers can develop (Friend 1966, Cooper and Tainton 1968, Ludlow 1974). Temperatures lower than optimum often increase the number of tillers and tiller life (Horrocks and Washko 1971, Cooper and Tainton 1968). Tillering can be increased by artificially inhibiting auxin transport from the primary axillary meristem (Stubbendieck and McCully 1976) or removal of the primary axillary meristem (Leopold 1949).

In legumes, early seedling growth and development (Cooper 1977, Dodds and Meyer 1979) and vegetative plant development (Dodds and Meyer 1979, Nelson and Smith 1968a, Singh and Winch 1974, Musgrave and Langer 1977) have been described. In alfalfa (Medicago sativa) cotyledons emerge above the soil surface (epigeal emergence) and the epicotyl develops into the first unifoliolate leaf. Subsequent leaflets are trifoliolate, having three leaflets. Axillary buds develop new stems from the axils of the cotyledons, unifoliolate and first trifoliolate leaf. After three or more trifoliolate leaves have developed on the main stem, the axillary buds become active and can develop branch shoots. Internode elongation from the first internode moves the apical meristem, primary and branch stems upward. Crown buds produce regrowth stems along with axillary buds on the branch stem. Reduced light intensity, shading, reduces the number of new stem branches (Ludlow et al. 1974), leaf thickness and stomata number (Cooper and Qualls 1967) and nodulation and nitrogen fixation (Butler et al. 1959). Reduced temperature generally decreases the infection and nodulation process (Gibson 1967a) and ultimately nitrogen fixation capacity (Gibson 1967b).

Sunlight is the energy source for plant growth. Leaf lamina and leaf sheaths contain chloroplasts necessary for converting light energy into chemical energy. Photosynthate produced largely by the leaf lamina can be utilized directly after synthesis or accumulated and stored by the plant (Williams 1964, Wardlow 1968). The architecture of the plant canopy determines how light will be intercepted, reflected and absorbed. Full sunlight reaches the top leaves and decreases in intensity as it is reflected and passes through the canopy. Beer's Law has been shown to best describe light distribution within the plant canopy (Brown and Blaser 1968).

$$I = I_o e^{-KL}$$

Where: I = the light intensity penetrating through a leaf area index (L) at a given height within the canopy

I_o = incident light energy at the top of the canopy

K = extinction coefficient for light energy

L = leaf area index from top to the height level measured

e = the base of the natural logarithum

Two important variables in the formula are the leaf area index (L) and the extinction coefficient (K). The K expresses a gradient of decreased light intensity as light passes through the canoy. Legume plants often have a $K > 1$, indicating the leaf lamina are positioned horizontally and much of the light energy is trapped with only a few layers of leaves. Grasses have more vertically inclined leaves allowing for more light to be evenly distributed throughout the canopy. K values are usually 0.3 to 0.7 for grasses (Brown and Blaser 1968). L was proposed by Watson (1947) and is defined as the amount of leaf area (one surface) per unit of ground area. L quantitatively measures the amount of foliage present or indirectly the amount of leaf area lost during defoliation. Most pasture mixtures are made up of one or more legumes and grass species. Thus, competition between the plant species for light is great. Plant height (Trenbath 1974), leaf area (Donald and Black 1958), and leaf angle (Langer 1973, Brogham 1958) are fundamentally important for the plant to be competitive in the mixture. Grass plants are usually taller than legumes, with a more desirable K, thus, generally grasses have the competitive edge in the mixture. Because many legumes have horizontally orientated leaves, they reach a critical leaf area index, "critical L" (amount of leaf area to intercept 95 percent of light), more quickly than grasses, light within the canopy becomes a critical factor relatively early in the growing season (Langer 1973).

Plant Growth In Pastures

Brougham (1956) clipped a mixed short-rotation ryegrass (*Lolium perenne* X *L. multiflorum*), red clover (*Trifolium pratense*) and white clover (*Trifolium repens*) pasture at 2.5, 7.5 and 12.5 cm heights. He determined the critical L of 5 and maximum regrowth to occur at 24, 16 and 4 days after defoliation, respectively. He proposed the critical L as the leaf area to achieve maximum photosynthetic capacity and growth rate. Brougham (1958) found different critical L for different species, 7.1, 6.5, 3.5, 4.5 for ryegrass, timothy (Phleum pratense), white clover and grass-clover misture, respectively.

Two relationships have been found relating dry matter yield to L. Yield increased as L increased to the critical L then declined (Brougham 1958). Increased L, as found in pastures, means more of the lower leaves are shaded. Maximum L's found for ryegrass, timothy, white clover and grass-clover mixture pastures were 9, 10.8, 5.5 and 7.3, respectively. Donald and Black (1958) propose that pastures should be managed to maintain as close to the critical L as possible, thus allowing for rapid regrowth of defoliated tissues and maintaining high light interception. Brown and Blaser (1968) using alfalfa, suggest that L has been oversimplified and light interception overemphasized. They found no decrease in dry matter yield above the critical L and yield increased to quite a high L level (10 to 11). This may be because the alfalfa canopy is unlike the true clovers and leaf angles allow for greater light penetration into the lower leaves. Brown and Blaser (1968) state "absorption of light by aged or senescent leaves and non-photosynthetic plant parts, such as stem bases, is wasteful and shading of the soil by such material may hinder production of new tillers". Their suggestion for some species, such as alfalfa, is to remove all topgrowth, thereby encouraging development of crown buds resulting in more seasonal dry matter yields. In some instances

L values below the critical level are advantageous because tiller and new branch stem production is encouraged. L values above the critical level are desirable when regrowth after defoliation is dependent upon stored non-structural carbohydrates (TNC) (Brown and Blaser 1968).

Leaf area and L are important for increased dry matter yield in the form of structural carbohydrates, and regrowth potential in the form of non-structural carbohydrates. Structural components such as cellulose, hemicellulose and lignin make up the bulk of the plant cell. Starch is the primary TNC stored in legumes and C_4 grasses (Jung and Smith 1961). Fructosans are the primary TNC in C_3 grasses (Smith 1968a, Ojima and Isawa 1968). TNC are necessary for providing energy in initiating spring growth and regrowth after defoliation, as reviewed by White (1973), Smith (1972) and Smith (1973). Early research demonstrated a seasonal cyclic pattern of TNC in base of leaves and stems of grasses (Reynolds and Smith 1962) and in roots of legumes (Jung and Smith 1961), where TNC primarily accumulate (Graber et al. 1927, Grandfield 1935, Sprague and Sullivan 1950, Sullivan and Sprague 1943, Wienmann 1961). In the fall, plants will store larger quantities of TNC for winter survival and initiation of new tillers in the following spring. During the vegetative growth of the plant, TNC levels decline to a minimum level. TNC levels increase dramatically as grasses reach the boot stage of growth. After defoliation a decline in levels occur with the regeneration of new leaf and stem tissue. TNC is rapidly replaced after sufficient leaf area is produced and maximum photosynthesis and growth rate occurs. For most forage species the highest TNC levels occur during flowering then decline slowly with seed maturation. Cooler temperatures generally increase TNC levels of grasses (Alberta 1957, 1965, Smith 1968a) and legumes (Smith 1968b).

Plants Resistance to Grazing

In a pasture environment, plants may or may not be grazed. Some plants resist grazing because of a type of protective armour, others may be grazed before or after the majority of plant growth occurs. Grazing of plants induces a number of morphological and physiological changes. Growth habit and palatability may all aid the plant. Marten (1969) presented as excellent review on the phenomon of palatability. He proposes palatability as a plant characteristic conditioned by plant, animal and environmental factors that stimulated selectivity for plants by the grazing animal (Marten 1978). Marten and colleagues studied the low palatability of reed canarygrass (*Phalaris arundinacea*) as compared to smooth bromegrass (*Bromus inermus*) and orchardgrass (*Dactylis glomerata*) (Marten et al. 1973, Marten et al. 1976, Simons and Marten 1971, Marten and Donker 1968, Marten and Anderson 1975, Jordon and Marten 1975). Marten (1978) lists the major plant, animal and environmental factors that influence palatability; these are:

	PLANT	ENVIRONMENTAL	ANIMAL
1.	Species	plant diseases	senses
2.	Intraspecific variation	soil fertility	species or breed
3.	Chemical composition	animal dung	individual variations
4.	Morphological or physical traits	feed additives	previous experience or adaption

5. Succulence or maturation	climatic variation	physiological conditions
6. Availability in non-controlled situations	seasonal or diurnal variations	
7. Form of forage controlled by mechanization		

Grazing Behavior of Livestock

Younger (1972) states "defoliation . . . means removal of varying amounts of top growth frequently including portions of stems as well as leaves". Harris (1978) proposes three parameters in defining defoliation: (1) frequency--time between successive defoliation; (2) intensity--amount of dry matter removed and subsequent changes in level of TNC; and (3) timing--growth stage of the plant and season of useage.

Tremendous interest in the grazing behavior of livestock on pasture, and how animals perceived forages, occurred after WWII. Excellent reviews of grazing livestock behavior have been published (Tribe 1955, Hafex and Lindsay 1965, Hafex and Schein 1962, Hafex and Scott 1962, Johnstone-Wallace and Kennedy 1944). While on pasture, animals perform a number of functions and phenomena. These include: grazing, rumination, loafing, resting, walking, deficating, drinking and others. Early investigators believed that understanding grazing behavior should allow for some influence on changes in pasture botanical composition due to selective grazing.

Large differences exist between ungulates in their defoliation of forage plants. The anatomy of the jaw, teeth and the capacity of the stomachs largely influences the intensity of defoliation. The sense of taste, touch, sight and smell often regulates the frequency and timing of defoliation. Grazing for most domestic ungulates is a relatively slow and time consuming process. Cattle spend between 4 to 9 hours per day in grazing (Gray et al. 1970, Hull et al. 1960, Hughes and Reid 1951, Lofgreen et al. 1957, Hancock 1954, Hafex and Schein 1962), while sheep graze from 9 to 11 hours per day (Hughes and Reid 1951, Hafex and Scott 1962). During the grazing process, cattle generally stand, but they will kneel on their forelegs to reach under fences, etc. The cattle consume food immediately under their muzzle and slowly move their head in a side to side or front to back motion for the next bite. Cattle have no upper incisor teeth, but have a very mobile tongue. The tongue encircles a mouthful of plants and draws it into the mouth. A pinch action between the tongue and teeth binds the forage so it can be torn off. Cattle cannot graze closer than about 15 mm from the soil because of their lower jaw. Sheep can graze nearly to soil level due to cleft upper lip. The tongue of sheep does not protrude from the mouth; rather the lips, lower incisor teeth and the dental pad are used for plant defoliation. The forage is severed between the lower incisor teeth and the dental pad with a quick forward-upward jerking motion from its head. Rumination time of 4 to 9 hours for cattle (about equal to grazing time) and 8 to 10 hours for sheep have been observed (Hughes and Reid 1951, Hafex and Schein 1962, Hafex and Scott 1962). Grazing time and rumination time can be influenced by quantity and quality of available forage. Hancock (1953) suggested that with high availability and good quality forage, cattle will have an intermediate grazing and a short ruminating time.

However, if quality is low, then grazing time is shortened and rumination time is increased. With low availability, forage quality did not influence grazing period (relatively long) and rumination time was short for good quality and intermediate for poor quality forage. Environmental conditions such as slope, watering and temperature all influence animal grazing behavior. Studies have shown that most grazing takes place during the daylight hours, largely at sunrise and sunset (Hughes and Reid 1951), with usually less than 1 hour grazing during the dark period (Gray et al. 1970).

Researchers have investigated the importance of the animal senses, sight, smell, taste and touch, in selecting the forage consumed (Arnold 1966 a,b, Tribe 1949 a,b, and Kruger et al. 1974). Chemical and surgical controls along with blindfolds impaired the senses in such a way so that they could be studied in forage selection processes. Taste appears to be the primary sense used in diet selection of grazing sheep. When taste was impaired sheep were unable to be as selective in their separating of palatable and unpalatable plants and genotypes within a species. The sense of smell apears to be complementary to taste for most plants. Of the more than 30 plant species studied (Arnold 1966 a,b, Tribe 1949 a,b, Kruger et al. 1974), only one forb appeared to be selected by smell rather than taste. Sight aided in selection of highly palatable, tall species. Low growing palatable plants appear not to be seen at distances of greater than about three meters. Touch was the least important, but supplemented the taste sense in diet selection. When all four senses were impaired the selection of low palatable species was increased in the diet and the amount of highly palatable species decreased. Grass plants were mainly selected by both taste and sight, legumes by taste and smell, and no generalization could be made for forbs.

Plant Regrowth After Grazing

The plant's ability to regrow after defoliation is primarily dependent upon L, TNC and growth habit. The most obvious effect of defoliation is removal of photosynthetic leaf area resulting in less CO_2 fixation. In studies where the leaf area was completely defoliated, it appears that TNC levels are the major energy source in tissue regeneration in both grasses (Davidson and Milthorpe 1966 a,b) and legumes (Hodgkinson 1970). With partial defoliation the remaining leaf area, if not senescent, contributes the greater amount of energy for regrowth from photosynthate rather than stored TNC (Smith 1974, Ryle and Powell 1975, Leach 1970, Painter and Detling 1981, Detlin et al. 1980, Kodgkinson et al. 1972). This response from partial defoliation is due to the increased or very slow declining net photosynthesis rate of the remaining leaves. Ryle and Powell (1975) found with partial defoliation that the amount of photosynthate transported from leaves to roots was greatly decreased with an increase from leaves to new leaf tissue which grew from 70 to 100 percent of the rate of control plants. Painter and Detling (1981) found a new photosynthetic rate of 114 percent for 10 day old western wheatgrass regrowth under a heavy defoliation.

Defoliation of the plant at a critical time in its growth stage can reduce tillering, dry matter yield and TNC. The critical time is different for different plant species; basin wildrye (Elymus cinereus) at boot stage (Perry and Chapman 1975); big and little bluestem and Indiangrass between floral initiation and anthesis (Vogel and Bjugstad 1968); black grama (Bouteloua eriopoda) at flowering (Miller and Donart 1979); mountain brome (Bromus carniatus) at flowerstock formation through seed maturation (McCarty and Price 1942); and in the fall for alfalfa (Smith 1962). Defoliation nearly always reduces root growth (Crider 1955, Fulkerson 1970, Oswalt et al. 1959) which is a response to reduced top growth. Crider (1955) found that removal of 40 percent of the top growth stopped root elongation in most grasses. Miller and Donart (1979) found 65 percent removal of black grama leaves reduced stolen formation.

Tissue regeneration also depends on the growth habit of the plant. Vegetative grass shoots have been described as culmed or culmless and the shoot apex may or may not be elevated (Branson 1953, Hyder 1972, Hyder and Sneva 1963). Shoots may also be reproductive, but these are under hormonal control. Auxin inhibits the development of axillary buds, but defoliation of the apical meristem removes the inhibition and allows the dormant buds to freely develop (Leopold 1949). Grasses with culmed vegetative shoots are crested wheatgrass (Agropyron cristatum) (Hyder and Sneva 1963), western wheatgrass (Enevoldsen and Lewis 1978), and Basin wildrye (Perry and Chapman 1975). The apical meristem of culmed grasses will become elevated by internode elongation, even in the absence of flowering and thereby vulnerable to grazing. If the growing point is removed by the livestock, regrowth may be slow and coming from new axillary buds and intercalary meristems of residual leaf tissue. Culmless vegetative shoot grasses such as orchardgrass, Kentucky bluegrass (Poa pratense), and bermuda grass (Cynodon dactylon), do not elevate their apical meristems within the vegetative shoots, and are seldom lost during the grazing process. Regrowth is relatively fast because the apical meristem stay near the soil surface producing new leaves.

Legumes also have differences in growth habits. Taller legumes, like alfalfa, are more upright with their apical meristems at the very top of the canopy. These meristems are very susceptible to grazing and must rely on crown buds for regeneration of stems (Langer 1973). Intermediate plants, like red clover, also have an upright growth habit, but this plant also has meristematic activity within the stipules. After grazing the tops of this plant, the stipules may produce new leaves and stems. White clover is prostrate in growth habit with very large leaves. In general, the more prostrate legumes are much better adapted to grazing than the intermediate, and the intermediate better than upright plants.

Grazing Pressure

Mott (1960) proposed a theory on grazing pressure and its influence on gains per animal and gain per unit land area. His method quantitatively evaluates a pasture in terms of equal dry matter of forage per animal unit rather than trying to make size of pastures equal. If grazing pressure is too light, then livestock are allowed to selectively graze only the most palatable plant species, resulting in the greatest gain per animal but low production per land area. With high grazing pressure, performance and gains per land area decline rapidly. With optimum grazing pressure, excellent animal performance and gains per land area are achieved. Although Mott's grazing pressure theory was developed years after our modern day grazing systems, it allows us as managers to look at the performance of the animal and land in proper perspective.

Grazing Systems

Several authors have proposed different definitions for grazing systems (Heady 1970, Hodgson 1979, Booysen 1967, Kothmam 1974, Range Term Glossary Committee 1964, 1974). This discussion will adapt terminology from the 1974 Range Term Glossary Committee. A grazing system is "a specialization of grazing management which defines systematically recurring periods of grazing". Lacey and Van Poolen (1979) and Lewis (1981) have developed dichotamous keys for the classification of grazing systems. The purpose of the key is to aid in standardizing the practical aspects of grazing terminology. All grazing systems are not effective for each livestock producer, and likely not effective on each pasture on a particular ranch. The purpose of a grazing system is as a management tool whereby the livestock producer can effectively utilize and produce forage and livestock efficiently. Thus, both the grazing livestock and the grazed plant must be managed to obtain economic and sustained biotic responses (Mott 1960). Grazing systems may be placed into four broad categories: continuous, rotation, deferment and zero grazing. The following discussion is a composite view of these grazing systems along with their advantages and disadvantages (Jefferies 1970, Kothmam 1974, Bryant et al. 1970, Watton et al. 1981, Watson and Runcie 1960, Charette et al. 1969, Harland 1956, Owensby et al. 1973, Shiflet and Heady 1971, Raguse et al. 1971, Smith et al. 1967, Heady 1961, Heinemann 1970, Raymond 1970).

Continuous grazing, also referred to as "set-stocking, free, or uncontrolled" grazing is defined as "the grazing of a specific unit by livestock throughout a year or for part of the year during which grazing is feasible". Continuous grazing does not mean that livestock must be grazed on the same pasture for the entire season, although this is common practice. Many researchers recommend continuous grazing if the pasture is predominantly grasses with culmless vegetative shoots. Some advantages of continuous grazing are:

1. Animals are free to select any plant part or plant during the entire period of use.

2. Pastures are understocked when plants are rapidly growing and defoliation per plant is slight. As regrowth occurs, defoliation is often more intensively grazed and pastures may be overstocked.

3. Minimum of livestock herding, movement, labor and fencing.

4. Quality of forage changes slightly from day to day.

5. Highest performance per animal.

Disadvantages of continuous grazing are:

1. Difficult to obtain equal grazing of pastures.

2. Difficult to adjust stocking rate in dry years.

3. Difficult to keep more palatable species in the stands and having the grazing resistant species becoming dominant.

4. Usually lower carrying capacity over the grazing period.

Rotational grazing is a "system of pasture utilization embracing short periods of heavy stocking followed by periods of rest for herbage recovery during the same season. Generally used on tame pastures or cropland pasture." Several subcategories of rotation grazing have been used. These include: rest-rotation, strip grazing, complementary grazing and short-duration grazing. Livestock on a rotation grazing system may defoliate plants within one hour or up to one week or more, depending upon the grazing pressure. Grasses with culmed vegetative shoots are best adapted for rotational grazing. Some advantages of rotational grazing are:

1. Pastures are grazed during optimum yield and growth stage while regrowth of previously grazed pasture occurs.
2. More even grazing of the pasture.
3. Essential if pastures are irrigated.
4. Greater carrying capacity on pastures.

Disadvantages of rotational grazing:

1. Requires more labor, fencing and watering sites.
2. Reduced grains per animal because increased stocking rates may cause livestock not to obtain enough nutrients in a normal grazing day.
3. Must use adapted species.

A deferred-rotation grazing system "provides for a systematic rotation of the deferment among pastures". Here a pasture is deferred for the grazing season or until the key plant species have produced mature seed. This is an excellent system on rangeland that is in less than good condition. A change in the order of pasture grazing occurs nearly every year so no pasture is grazed at the same time year after year. Grazing is deferred on the designated pasture during the critical time for the plants and allowing for maintenance or increased abundance of desirable species. Advantages of deferred-rotation grazing are:

1. Smaller pastures forces livestock to graze plants normally not selected.

2. Rotating livestock reduces repeat grazing of more palatable plants allowing them to become more vigorous.

3. Often forage yields increase over a period of years.

Disadvantages of deferred-rotation grazing are:

1. Requires more labor, fencing and watering sites.

2. Must avoid overgrazing in early part of grazing period.

3. Must take land topography into consideration when dividing pastures.

Zero grazing or "soiling or greenchopping" is a system whereby herbage is cut fresh daily and fed to livestock in drylot. Some advantages of zero grazing are:

1. Complete removal of plants so pastures are better utilized with little storage and field losses.

2. Plant regrowth is uniform and land is kept neat and clean.

3. Livestock eat more in drylot allowing for increased gains per animal and gains per land area.

4. Favors efficient utilization of forage during optimum yield and quality stage of growth.

5. Store excess forage for future need.

Disadvantages of zero grazing are:

1. Very labor intensive.
2. High cost for purchase and maintenance of machinery.
3. No natural return of manure and urine to soil.
4. Livestock cannot select daily diet.

Lewis (1981) stated "grazing systems are not a magical cure-all, but are an important and integral part of grazing management". A grazing system must be manageable and flexible so it can be adapted to unpredictible events that cause changes in growth and quality of plants. Generally, failures of a system are not due to the system of grazing but in management where the manager did not take into account the basic principle of forage crop growth and regrowth.

IV. Perspectives on Forage Quality Importance

The terms "forage quality" or "feeding value" are used widely by animal nutritionists, range and forage specialists alike. While being inherently nebulous the terms are still useful in the evaluation of forage for livestock. Barnes and Marten (1979) define these terms as "the type and amount of digestible nutrients available to the animal per unit time; forage quality is a function of the rate and level of intake, the rate and extent of digestion, and the efficiency of utilization of specific nutrients. Any or all of these functions may be inhibited by the presence of anti-quality substances in specific forages." Past research has shown that maximum dry matter yield and forage quality cannot be obtained simultaneously (Weir et al. 1960). An understanding of modern day forage quality measuring techniques is essential in deciding how to best utilize these resources.

Historical View

The oldest system for forage analysis is the Weende system; the origin of this system is older than we know. "Einhoff, as early as 1809, prepared fiber by extraction with alcohol, dilute acid and alkali" (Van Soest 1964). The fiber content is referred to as crude fiber. Einhoff considered this fiber to be the indigestible portion of the feed and made estimates of nutritive value based on the fiber. The Weende system was developed about 1860 by Henneberg and his colleagues at the Weende Agricultural Experiment Station in Germany. The Weende system is also known as the "proximate analysis". The proximate analysis estimates the digestible portion of the feed, whether it be of high or low fiber content, like forages (roughages) or grains (concentrates), respectively. The proximate analysis, estimates total digestible nutrients (TDN) which represents the gross energy of the feed minus the energy in the animal feces and is defined as (Morrison 1956):

TDN = digestible protein + digestible fiber + digestible fat x 2.25 + digestible nitrogen free extract

A major problem with the TDN system was that in some cases crude fiber was more digestible than nitrogen free extract (NFE), the most digestible part of the feed. Upon further analysis, lignin was found to be the indigestible portion of NFE. The TDN system in some cases will overestimate the nutritive value of roughages and underestimate the value of concentrates. NFE is found to be the most variable fraction of the TDN system because it is not an analysis but a calculated value, and thus contains the cumulative errors of all the other analysis within the Weende system (Van Soest and Robertson 1980). Other problems with TDN is the use of 6.25 as a factor to convert percent nitrogen to crude protein. Crude protein refers collectively to the sum of the 20 plus amino acids. True protein involves only about 70 to 80 percent of feed nitrogen and very minute amounts in the feces. Thus, the 6.25 factor for all feeds and feces nitrogen ultimately produces errors that occur in NFE (Van Soest and Robertson 1980). Fat or ether extract may also be a source of error because roughages are typically low in fat and some plant compounds, such as chlorophyll, are soluble in ether.

Chemists and animal nutritionists concluded that a more satisfactory method of partitioning digestible and indigestible carbohydrates of feeds was needed. Many methods were proposed; one of the better was by Crampton and Maynard (1938). They partitioned crude fiber into cellulose and lignin, giving a better index of nutritive value. Unfortunately, some hemicellulose is associated with the lignin fraction and variable lignin responses are found with lignin when crude protein was high (Van Soest and Robertson 1980). Many other methods have been proposed to displace crude fiber as the official fiber test method, but none have been successful.

In 1948, McDougall characterized the composition of sheep saliva. A solution known as "artificial sheep saliva" became the buffer solution to be used in the in vitro dry matter digestibility (IVDMD) procedures. Burrough et al. (1950 a,b) using artificial sheep saliva with different trace elements and rumen liquor developed the first "artificial rumen" or IVDMD procedure. The method was tested and improved upon when Tilley and Terry (1963) added a second step to stimulate digestion of protein in the abomassum. A high correlation between in vivo dry matter digestibility and IVDMD has been shown by numerous workers (Tilley and Terry 1963, Kamstra et al. 1973, Monson et al. 1969, Reid et al. 1964, Monson and Reid 1968, Barnes 1965). The IVDMD method has been termed "batch-culture" where all the nutrients are initially supplied and gradually replaced with waste products of digestion over time. A second method of IVDMD "continuous-culture" has been introduced, where the nutrient substrates are replenished and waste products removed over an extended period of time (Ewart 1974). This system has been viewed as superior to the batch-culture because it more closely resembles in vivo digestion.

Van Soest (1963 a,b) proposed the concept of partitioning the plant cell into cell contents and cell wall constituents. This procedure uses acid and related detergents to fractionate the plant cell. His approach was to determine the most important fractions found in both the roughage and feces (Van Soest 1967). The cell contents, containing cell organelles, non-protein nitrogen, protein, lipids and other cell solubles, were removed from the plant using neutral detergent. The products remaining from neutral detergent fiber (NDF) analysis are the cell wall constituents (CWC). The CWC are composed of cellulose, hemicellulose, lignin, cell wall nitrogen and minerals including silica. The CWC are treated with an acid detergent solution resulting in acid detergent fiber (ADF). The acid detergent removes hemicellulose and cell wall nitrogen, leaving a cellulose, lignin and mineral residue. The ADF residue can be treated with 72 percent sulfuric acid to dissolve the cellulose leaving a lignin and mineral fraction. Ignition of the remaining sample will burn off the lignin, leaving minerals or ash. The detergent system proposed by Van Soest has several advantages over the TDN system:

1. It gives a more correct description of the digestible nutrients of the feed.

2. The plant cell is partitioned into more useful components and the entire cell wall can be characterized.

3. A high correlation has been established between ADF and dry matter digestibility and between NDF and dry matter intake (Van Soest 1965).

Within the last ten years, researchers have developed new guidelines for evaluating forage and establishing a standard grading hay system (Rohweder et al. 1978). The Van Soest detergent system, *in vivo* dry matter digestibility, crude protein and stages of plant maturity are used to determine digestible dry matter, dry matter intake and relative feed value (RFV) for legume and grass hays. Legumes have been given grades 1, 2, 3, 4 and 6 or sample grade. Grass hays are given grades 2, 3, 4, 5 and 6 or sample grade. Thus, the best grass hays are considered to equal legume hay grade 2. For legume hay to be grade 1, it must have greater than 19 percent crude protein, less than 31 and 40 percent ADF and NDF, respecitively, and an RFV greater than 140.

Forage Quality From The Plant's Viewpoint

Plants are a heterogenous complex of cells and tissues, differentiated into leaves, stems, flowers and roots. Each cell cytoplasm is surrounded by a plasma lemma and bounded by a cell wall. The cytoplasm or cell contents contain organelles and nutrients in an aqueous solution. The cell wall performs two main functions: adds strength and provides for plant form while still being elastic enough to allow for continued cell growth. The cell wall consists of several major components: cellulose, hemicellulose, and pectin. Variable amounts of lignin, tannins, resins, proteins and silica also contribute to the plant cell wall. The secondary cell wall is chiefly lignin with some hemicellulose, while the primary cell wall is made up of other cell wall components.

Ritter and Kurth (1933) coined the term "holocellulose" which refers to the hemicellulose-cellulose complex. Holocellulose means whole or entire cellulosic material. Early chemists believed hemicellulose was a precursor of cellulose. Today, hemicellulose is classed as a non-cellulosic polysaccharide (Bailey 1973). Pectin and hemicellulose are both amorphous by physical nature. Pectin functions primarily as an intercellular cementing agent and hemicellulose adds to both the cell wall fiber and amorphous matrix. Pectin is made up of D-galacturonic acid units linked with alpha 1,4 bonds on the main chain and alpha 1,2 linkages of L-rhamnose on side chains (Bailey 1973). The L-rhamnose sugar causes kinks in the normally straight chain. These kinks allow for openings to form within the polygalacturonic chain where the cations Ca^{+2} or Mg^{+2} can insert and form bridges. These bridges are bonded strongly and add to overall cell wall strength (Preston 1979).

Hemicellulose is divided into two broad classes: pentosans and hexosans. Pentosans may be based on either xylose or arabinogalactan. Xylose or xylan is found in most grasses and legumes with a beta 1,4 D-xylopronose main unit chain and side chains of L-arabinose, D-glucuronic acid, D-galactose or D-glucose with alpha 1,2 alpha 1,3 or alpha 1,4 linkages (Bailey 1973). Arabinogalactan is mainly found in gymnosperms. Hexosans are based on mannans and beta-glucans. In forage crops beta-glucans predominate, having D-glucose molecules linked with a beta 1,3 linkage. One major difference between the pentosan and hexosan hemicellulose classes is that pentosans have branched chains with the possibility of many side branches whereas hexosans are helical in nature. The helical nature of beta-glucan has been linked with the possible role in cell wall elongation (Preston 1979). Van Soest (1964) reports that qualitatively hemicellulose consists of from 6 to 40 percent of dry matter. Bromegrass and orchardgrass have about 30 and 40 percent, respectively, and alfalfa averaged about 9 percent. Kamstra (1973) and Cogswell and Kamstra (1976) reported percentages of xylose, arabinose, galactose and glucose for six cool and warm season grasses and one sedge during the growing season in South Dakota. Generally, plant species were different in their sugar concentrations. Xylose and arabinose levels were higher in cool-season grasses and warm-season grasses were higher in galactose and glucose. Xylose and arabinose sugars increased in concentration during the season while galactose declined and moderate fluctations occurred with glucose.

Cellulose is the most abundant organic compound on earth and in some plants, such as cotton, cellulose can make up 95 percent of the cell wall (Wood 1968). Three types of cellulose are known to exist: beta 1,4 D-glucopyranose; beta 1,3 D-xylopyranose; and beta 1,4 D-mannopyranose (Preston 1979). D-xylose is chemically identical to glucose except the number six carbon does not contain the $-CH_2OH$ unit. D-mannose differs from glucose only in the -OH position at carbon two. The cellulose disaccharide, cellobiose, is very stable allowing for the condensation of many sugar units at both ends to form a flat, straight, ribbon-like molecule. The cellulose may contain up to 10,000 glucose molecules. These fibers are parallel arranged (Gardner and Blackwell 1974), and through hydrogen bonding form microfibrils ranging about 200 A wide and 100 A thick (Preston 1965). Microfibrils are randomly laid and condensed into micelles. Micelles are condensed to form macro-fibirls, the primary supporting structure of the cell wall. About 30-35 percent of cool-season grass dry matter is of cellulose (Van Soest 1964 Cogswell and Kamstra 1976). Warm-season grasses generally range from 35-40 percent of dry matter as cellulose (Cogswell and Kamstra 1976). Alfalfa and alfalfa-grass mixture pastures have been reported to have about 25-30 and 20-25 percent of cellulose, respectively (Campbell and Dotzenko 1975, Thompson and Dotenzko 1977, Van Soest 1964).

Lignin is the most variable and difficult fraction of the cell wall to define. Lignin is derived from phenylpropanoids, where penylalanine and tyrosine are used as precursors (Albersheim 1965, 1976). The three main phenylpropanoids are: p-coumaryl, coniferyl, and sinapyl alcohols interconnected at random producing a "syrup" like substance that seeps into pores and between layers of cellulose and hemicellulose in the primary cell wall, while also forming a secondary cell wall. Unlike hemicellulose and cellulose levels that remain relatively constant throughout the growing season, lignin levels are usually low early and increase with plant maturity (Campbell and Dotzenko 1976, Thompson and Dotzenko 1977). Legumes generally contain twice as much lignin as grasses (Van Soest 1964).

Cutin is a non-aromatic structure often found on plant surfaces and is chemically measured as lignin in the Van Soest detergent system. Upon treating ADF with permanganate to oxidize lignin, and then with 72 percent sulfuric acid, cutin can be isolated (Van Soest and Wine 1968).

Silicon, as an amorphous silica or silica gel, is the major mineral element deposited in plant cell wall of grasses (Jones and Handreck 1967), and in the cell lumen (Lanning et al. 1958). Silica solubility is not influenced by soil pH of 2 to 9, but solubility increases dramatically above pH of 9 (Jones and Handreck 1967). The silica mineral is easily absorbed and transported via the xylem transpiration stream and then bonded mainly above ground plant parts, although some silica is accumulated in the root systems. Lanning and Linko (1961) grew four sorghum (Sorghum spp.) varieties in field studies. After 20 days of growth they found relatively low amounts (less than 4 percent) of silica in the leaves and first leaf sheath. However, roots contained over 15 percent silica in one variety and over 10 percent in two others. At 40 days of growth silica content of all varieties was less than five percent of dry matter in the roots, but leaves and first sheath were increasing at a linear rate. Stems and seeds of sorghum accumulated very small amounts of silica. After 140 days the first sheath of two sorghum varieties contained nearly 20 percent of the dry matter as silica. Lanning (1963) studied silica accumulation of rice (Oryza sativa L.) in different plant parts at the boot stage. Rice roots, stems, leaves, sheath and inflorescences contained 5.8, 5.1, 10.1, 3.1, and 2.6 percent of dry matter, respectively. Jones et al. (1963) compared total silica and opaline silica percentages in various mature oat plant parts. They found percent silica of 10.36, 1.42, 5.34, 4.55, 1.84 and 0.12 for nodes, internodes, leaf blade, leaf sheath, root and seed, respectively. Generally, opaline silica values were similar to total silica except for nodes where oaline silica was 1.56-1.74 percent rather than 10.36. Parry and Smithson (1966) describe different shapes of opaline silica bodies in grasses, some of these are: spongy silica (associated with mesophyll cells), dendriform opal, cork cell opal, hats, sculiform opal and round spiky opal.

Recently, Geis (1979) studied opaline silica concentrations in three warm-season grasses collected in December. Indiangrass contained 5.6 percent silica, as compared to switchgrass (4.4 percent) and big bluestem (4.1 percent). Silica levels of: leaf blades were 6.79, 5.00 and 9.44; leaf sheath 3.78, 3.38, and 6.25; culms 0.64, 0.97, and 1.79 for big bluestem, switchgrass and indiangrass, respectively.

Silica, much like lignin, percentages are relatively low in early spring and increase during the growing season to where they may have more than doubled by early fall (Campbell and Dotzenko 1975, Thompson and Dotzenko 1977).

Environment effects can also play a major role in determining forage quality of plants. Van Soest et al. (1978) have summarized some of the more important environmental effects and their influence on different aspects of forage quality, these are shown below.

Component	Temperature	Light	Nitrogen	Water	Predation
Yield	+	+	+	+	-
Nitrate	-	-	+	NA*	NA
Cell Wall	+	-	+	+	-
Lignin	+	-	+	+	-
Digestibility	-	+	+	-	+
Water-soluble carbohydrates	-	+	-	-	+

*Not Available

Van Soest et al. (1978) concludes "factors that retard plant development will promote the maintenance of forage quality for a longer time".

Forage Quality From An Animal's Viewpoint

The main purpose of forages in the diet of ruminants is to provide energy to the grazing animal (Reid et al 1959). One method of measuring forage quality is by measuring the response of the free grazing animal to the herbage consumed (Mott 1959). Under grazing conditions, high forage production without proper management to maintain digestible forage quality may actually be counter-productive (Beaty et al. 1980). From these points of view it is understandable why we should not underestimate the influence of forage quality and ultimately the amount of energy in the forage as it affects animal performance. Mott (1959) describes the importance of forage quality on animal output or performance as a function of rate of intake and nutritive value. Nutritive value is a function of in vivo digestibility and the chemical composition of the plant. Rate of intake is a function of palatability, rate of passage, grazing pressure and environmental effects on the animal (Barnes 1965). The apparent in vivo dry matter digestibility of a feed is defined as:

$$\text{In vivo digestibility} = \frac{\text{dry matter feed} - \text{dry matter feces}}{\text{dry matter feed}} \times 100$$

The concept of digestibility is not only useful for dry matter, but applies to different feed fractions such as cell walls, lignin, energy and protein. Van Soest and Moore (1965) have estimated true dry matter digestibility to be 12.9 percent greater than apparent digestibility. The difference is due to losses from metabolic and bacterial residue. When evaluating the digestibility of plant components, from both the cell wall and the cell lumen, it is important to keep in mind the high correlation between in vivo dry matter digestibility and IVDMD.

Forage nutritive value is the digestibility of the chemical composition of the plant cell contents and CWC (Mott, 1959). The average true digestibility of cell contents for both ruminant and nonruminant animals is approximately 98 percent for forages and concentrates (Van Soest 1967). The cell contents are considered to be nearly available for animal use. About the only limiting factors are the possible production of fecal soap and rate of passage that may be found with lipids and starch, respectively (Van Soest 1969). The CWC, which represent the total fiber fraction, are more variable in their digestibility (Van Soest 1967). Hacker and Minson (1981) have provided an excellent review of the digestibility of various plant parts (i.e. stems, leaves, tuber, etc.). Our discussion will be more concerned with the digestibility of CWC, individual cell types within major tissues and their effect on intake, rate of fermentation and passage in the animal.

Lignin is the most indigestible fraction of the cell wall. At pH levels that normally occur in the rumen, lignin solubility is near zero. However, a pH range of 9 to 13, lignin solubility increases from about 50 to 90 percent (Van Soest 1967). As noted earlier, cellulose and hemicellulose concentrations in the plant tend to vary only slightly during the growing season, whereas lignin production steadily increases. Digestibilities of cellulose and hemicellulose become highly correlated with lignification as the growing season progresses (Van Soest 1967). Smith et al. (1971) found lignin to protect about twice its own weight in structural carbohydrates from digestion. Lignification is the major component regulating the digestibility of both cellulose and hemicellulose within the animal (Van Soest 1967). This supports the observation of many researchers who have found a net decrease in forage IVDMD as the season advances (Campbell and Dotzenko 1975, Thompson and Dotzenko 1977, Newell and Moline 1978). Lignin is limited to the cell walls, it does not affect the cellular contents (Van Soest 1967). It is now possible to understand why grasses, with a relatively low lignin concentration can have about the same digestibility as legumes with two or more times the lignin percentage (Raymond 1969). Van Soest (1980) proposed the term "nutritive differentiation" when referring to the distribution and degree of lignification. Environmental conditions, plant species and plant parts all influence nutritive differentiation. Harkin (1973) has reviewed the literature, separating grasses and legumes by plant parts as to the degree of their lignification. Mature grasses generally follow a pattern of lignification from high to low of: stem, sheaths, infloresence and leaf blade. Legume stems contain about twice the amount of lignin as the leaf blades. Few observations have been taken on the petiole as to their rank. However, petioles appear to be about equal to leaf blades in lignin concentrations.

Hemicellulose percentage is much higher in grasses than legumes, which helps account for the higher cell wall percentage (Van Soest 1964, Sullivan 1966). In the rumen, available cellulose and hemicellulose can be digested by enzymes secreted from microorganisms (Leng 1973). Digestibilities of cellulose and hemicellulose have been reported by Sullivan (1966) and Keys et al. (1969). Sullivan (1966) used ruminants and seven different forages and found digestibilities from 58.7, 59.6, 61.3, 66.5, 71.6, 72.1, and 75.5 for hemicellulose, and 66.1, 61.5, 64.9, 69.6, 74.7, 77.0 and 80.1 for cellulose, legume silage, alfalfa, reed canarygrass, timothy, bromegrass, orchardgrass and Kentucky bluegrass, respectively. Because of the close comparison in digestibility of hemicellulose and cellulose, Van Soest (1975) has questioned if there is any nutritional advantage in discussing these two cell wall components independently.

Beaty and Engel (1980) and Beaty et al. (1982) have compared the digestibility of green vs. dead leaves and stems. Their contention is the IVDMD of green leaves may be 69 percent or more than dead leaves and conclude that the decrease in forage digestibility and nutrient concentration as the season advances in part reflects the accumulation of dead forage and stems (Beaty and Engel 1980). Leaves die mostly due to the shading from new leaf material and old age (Sampaio et al. 1976, Beaty et al. 1978a). Ode et al. (1980), following the changes in green and dead biomass, found large accumulations of green plant material from April 30 to June 16. After June 16 to October 8 green biomass declined at a near linear rate as dead biomass continued to increase. Nutritive differentiation and advancing maturity resulted in a decrease of green leaf and an increase in dead leaf material containing less nutrients.

The use of the scanning electron microscope and rumen fluid for digesting cell wall components has made it possible to study degradation of individual cell types in C_3 and C_4 grasses, legumes and ensiled crops. Most of the research on cell digestion has been conducted with green leaves with some studies on stems and sheaths. Profound differences in cell makeup within the leaf tissue may be one major reason why typically C_4 grasses averaged about 10 percent more cell walls than C_3 species (Van Soest et al. 1978, Van Soest 1973). C_4, As compared to C_3, grasses also have higher cellulose and lignification, lower TDN, and smaller numbers of desirable cell types within the leaves and stems accounting for an overall poorer quality (Van Soest et al. 1978).

Cell types common to grass leaf blade include: epidermis, mesophyll, parenchyma bundle sheath, sclerenchyma an the vascular system, composed of xylem, phloem, and inner bundle sheath (Esau 1965).

C_3 vs C_4
physical

Large differences between arrangement, thickness and amounts occur for cell types between C_3 and C_4 grasses. C_4 grasses have more vascular tissue, less mesophyll cells in a more regular arrangement, thick-wall parenchyma bundle sheaths and higher amounts of epidermis than C_3 species (Amos and Akin 1978, Akin 1980, Akin and Burdick 1975, 1977, 1981, Hanna et al. 1973, Akin et al. 1975, Barton II et al. 1977, Brown 1958). Akin et al. (1977) compared the amount of cell types and IVDMD on the top and bottom sides of bermudagrass leaves, sheaths and stems. Leaf blade tops contained more mesophyll cells (37.6 vs 28.9 percent) than blade bottom, with only a slight difference in other cell types. Sheath mesophyll percentages on top and bottom were identical (59 percent), with tops having more phloem. Stem cell types did not differ between top and bottom. When fiber and lignin percentages were compared, top portions of the leaf blades appear to have more CWC, crude protein and hemicellulose than the bottom portion. No real differences were found in IVDMD between the two leaf parts. Sheath tops, compared to sheath bottoms were higher in crude protein and hemicellulose but much lower in lignin (5.0 vs 8.5 percent) and had a greater IVDMD (56.8 vs. 43.5 percent). Stem tops were higher in crude protein and in IVDMD (61.0 vs. 45.2 percent), lower in CWC (67.0 vs. 78.3 percent), lignin (4.6 vs. 7.9 percent and cellulose (29.9 vs. 35.7 percent) over stem bottoms.

Rumen microorganisms, both bacteria and protozoa, break down plant material into a usable form for the animal. Rumen bacteria can attach to plant cell walls by at least two modes (Akin 1976). First, through direct attachment and secondly, for some types of bacteria (Cocci) a capsule-like substance about 58 nm in width was needed for attachment. Protoza seem to attach directly to plant cell walls in C_3 grasses but not C_4 grasses (Amos and Akin 1978). Amos and Akin (1978) evaluated three C_3 and three C_4 grasses, within two to five hours after inoculation with protoza, they found chlorophyll from the C_3 grasses was digested. The protoza attached and degraded the leaf mesophyll cell first followed by leaf epidermis and parenchmy bundle sheath within 24 to 48 hours. Relatively few protoza were associated with the C_4 grass leaves and they appeared to be nonmotile and not digesting plant cell walls. The following reasons were proposed for such an unusual observation:

1. C_3 grasses can have more than 50 percent of the leaf composed of mesophyll cells compared to 25 percent for C_4 grasses.

2. Mesophyll cell arrangement in C_3 grasses are loose and irregular with large amounts of air space between them and the vascular bundles. C_4 grasses have densely packed and radially arranged mesophyll cells around the vascular bundles.

3. C_4 mesophyll cells may be more rigid so protoza could not invade them.

4. C_3 grasses have starch grains in both mesophyll and parenchyma bundle sheath whereas in C_4 grasses starch is stored mostly in the parenchyma bundle sheath which is more rigid.

Rumen bacteria appear to attach around the thick cell walls of the epidermis and bundle sheath before degrading these tissues (Akin et al. 1974). To degrade the epidermis, bacteria must first degrade the area immediately below the cuticle, then the epidermal wall. The cuticle never becomes degraded. Sclerenchyma cells inside the leaf tissue are incompletely degraded. The mesophyll and phloem cells can be degraded even without bacterial attachment (Akin et al. 1973). The following relationship in tissue degradibility by rumen bacteria seems to exist for both C_3 and C_4 grasses:

Mesophyll and Phloem	>	Epidermis and Parenchyma bundle sheath	>	Sclerenchyma	>	Lignified vascular tissue

Digestibility of corn and sorghum leaves and stem silage and alfalfa hay were compared by Harbers and Thouvenelle (1980) and Brazle and Harbers (1977). In both studies, rumen bacteria were much more active on the adaxial (top) leaf surface rather than the abaxial (bottom). Bacterial activity accounted for nearly all the adaxial epidermis surface digestion while the abaxial epidermis surface was virtually intact. In corn and sorghum, abaxial epidermis surface had more stomata but no veins or macrohairs as compared to the adaxial surface which had hairs, bristles and stomata (Harbers and Thouvenelle 1980). Alfalfa veins and hairs were only found on the abaxial surface with stomata found on both. Brazle et al. (1979) investigated big and little bluestem digestion and found these native species were much more resistant to bacterial degradation than improved cultivars of bermudagrass. They also found that silica and possibly cutin were the main structural inhibitors, the cells with silica resisted collapse, even mesophyll cells. Dinsdale et al. (1978) provided evidence for differences in digestibility of mesophyll cell walls and regions within the same cell wall. These differences may be due to silica impregnated within the cell walls (Dinsdale et al. 1979). These studies support the results of Brazle et al. (1979) that silica may be a major factor in determining the digestibility of mesophyll cell walls. In an attempt to overcome the inhibitory effect of lignin, Spencer and Akin (1980) and Barton II and Akin (1977) used two different approaches but found positive results in both cases. Spencer and Akin (1980) used potassium hydroxide to separate parenchyma bundle sheath, inner bundle sheath and sclerenchyma tissues. They found that mesophyll cells with lignified tissue, treated with alkali degrade relatively easily whereas untreated cells were resistant to bacterial breakdown. Barton II and Akin (1977) used permanganate to dissolve lignin from the cell walls of normally lignified tissues. They found increases in bacterial degradation with sclerenchyma cells, but less so with vascular bundles from both C_3 and C_4 grasses. Their data suggests that possibly other inhibitors, such as silica, may impede the degradation of vascular bundles when lignin is not a barrier.

Morrison (1980) compared five C_3 grass species as to their lignin and hemicellulose concentrations. The hemicellulose was fractioned into branched and unbranched chains and percentages of neutral sugars. Lignin and hemicellulose were highest in timothy and orchardgrass, intermediate in diploid ryegrass, and lowest in tetraploid ryegrass. Timothy and orchardgrass had the highest ration of xylose:arabinose sugars and branched:unbranched xylan chains.

Galactose and glucose sugars were relatively low. These data support those of Kamstra (1973) and Cogswell and Kamstra (1976) for C_3 grasses. These studies indicate that with C_3 grasses arabinose and xylose percentages increase with plant maturity. Xylose and arabinose are very important as to the basic structure of hemicellulose, and this structure may be the basis for regulating hemicellulose degradation (Gaillard 1965, Bailey and Gaillard 1965). Hemicellulose is covalently bonded to lignin, probably at the xylose and arabinose sugars (Hungate 1966, Pidgen and Heaney 1969). Because of these covalent linkages between hemicellulose and lignin, during the catabolism of hemicellulose essentially no free xylose or arabinose sugars are found. Rather, xylose and arabinose oligosaccharides increased indicating portions of the hemicellulose complex may not be readily digested. Dehority (1967) found several strains of bacteria that were normally considered hemicellulose digesters that could not metabolize free xylose or arabinose. In a review of hemicellulose degadation, Dehority (1973) indicated that the lack of utilization by a particular strain would appear to be the inability of the organism to transport the oligosaccharide across the cell membrane or a lack of necessary enzymes to ferment these substrates. From the above studies it appears that cell wall degradation, even of the easily digested mesophyll cells, is controlled by structural inhibitors, such as silica and hemicellulose covalently bonded to lignin.

Van Soest and Jones (1968) evaluated C_3 and C_4 grasses and legumes to determine the effect of silica upon forage dry matter digestibility. Silica was not important in legume forage digestibility; however for grasses, each percent unit increase in silica corresponding decreased IVDMD three percentage units. Parry and Smithson (1963) artificially damaged grass leaves to stimulate partial defoliation. When leaf blades were notched or the apical portion removed, large amounts of silica were deposited near the point of injury just six weeks after the start of the study. They theorize that this increase in silica deposits may "have a bearing on the recovery and subsequent palatability and digestibility of grass herbage after several partial defoliations such as would occur under any grazing system."

The general importance of voluntary intake has been recently reviewed (Baile and Forbes 1973, Baile 1975, Forbes 1977, Waldo 1969) and specifically on grazing animals (Ellis 1978, Cordova et al. 1978). Forbes (1977) describes two major types of control: metabolic and physical. Physical is often referred to as gut fill or distention. Generally animals on high roughage rations, such as pasture, will eat until some part of their digestive tract is full of undigested plant cell wall material; this is gut fill. Thiago et al. (1979) has confirmed that gut fill theory by showing the rumen contained about the same amount of dry matter over a range of forage qualities. Jones (1972) demonstrated that different grass species with the same level of digestibility could give different animal performances. Voluntary intake or dry matter intake is positively correlated with rate of passage, and thus differences in intake can be due to the rate of passage and total capacity of the animal's digestive system (Van Soest 1975, Moseley and Jones 1979). Smith et al. (1971) studied the rate of digestion of three C_3 grasses and alfalfa. Digestion and NDF varied from 5.6 to 27.0 and 69 to 33 percent per hour, respectively. Higher CWC are associated with lower rates of digestion. Increasing the rate of passage due to increased feed intake results in decreased digestibility of the dry matter present in the digestive system (Tyrrell and Moe 1975, Van Soest 1975, Mertens 1977, Riewe and Lippke 1969). Ellis et al. (1979) reviewed the basic principles in the turnover of forage material in the rumen, but Van Soest's (1975) "Hotel Theory" best describes the interrelationships between cell wall degradation and dry matter intake. He made the analogy of the destruction of plant cell walls to that of a hotel. Viewing each cell in the blade or stem of grass as a single room in the hotel, the furniture can be removed and the hotel remain standing. Some of the less important interior walls can also be removed and the structure remains intact. Only when the supporting structures are demolished does the volume decrease and the hotel collapses. This is how one can view the degradation of plant cell walls. Van Soest concludes "this may explain why cell wall, the total structural matter of forages, is the most important plant factor affecting voluntary intake."

MATERIALS AND METHODS

Grazing Phase

This study was conducted at the Pasture Research Center located 1.6 Km north of Norbeck or 25.7 Km northwest of Faulkton, Faulk County, South Dakota. The 1079 ha ranch is representative of soil, precipitation and growing season for much of central South Dakota and typical of much of the Northern Great Plains.

Pasture management systems tested were a native range and a native interseeded range, a native range interseeded with 2.2 kg/ha 'Travois' pasture type alfalfa. The tame pasture series consisted of well-established pastures of crested wheatgrass, smooth bromegrass and alfalfa mixture, 'Piper' sudangrass (Sorghum bicolor) and Russian wildrye (Elymus junceus). Piper sudangrass was seeded each year at 28 kg/ha. Crested wheatgrass, Piper sudangrass and Russian wildrye were fertilized yearly with 73 kg/ha of nitrogen.

Cracked corn was fed on pasture daily at three levels: 0.0, 0.5 and 1.0 percent of body weight. Grain levels were computed by using the average weight of animals on pasture adjusted at the beginning of each weighing period. Salt and minerals were supplied by blocks in each pasture. A put-and-take system of stocking was used to keep grazing pressure about equal between pastures.

Weaned Hereford steers were purchased each fall in 1976 to 1978. Steers were fed a high roughage ration with protein and energy supplments in drylot during the overwintering period. In the spring and at termination of grazing, steers were weighed, shrunk overnight without water or feed, and weighed the following day. Initial spring weights and final fall weights were taken at the headquarters. Intermediate weights were taken with cattle on pasture (Tables 1 and 2). Initial shrunk weights were ranked from heavy to light and stratified to average weight differences between animals per pasture. Steers were implanted with Synovex S and treated for flies before going on pasture. Pasture treatments were in a factorial design with replications nested within pastures with three replications per treatment. Due to the design, a Quasi F test was required to separate some treatment means and interactions. Each steer was considered as 0.7 animal units (AU) and the following formulas were used to calculate animal and pasture performance:

1. Calendar days = last day on pasture - first day on pasture.
2. Grazing days = calendar days x number of grazing steers.
3. Total animal units = grazing days x 0.7 AU.
4. Average daily gain = final weight - initial weight/calendar days.
5. Animal unit months = total animal units/30 days per month.
6. Total gain = average daily gain x grazing days.

Table 1. Sampling dates of forage and animal weight dates by pasture period for native range and native interseeded ranges, 1978-1979.

Pasture Period	Forage Sampling Dates 1978	Forage Sampling Dates 1979	Animal Weight Dates 1978	Animal Weight Dates 1979
1	June 13	June 11 June 26 July 10	May 23-June 6	June 14-July 18
2	June 13 June 26 July 10	July 24 Aug. 8	June 6-July 18	July 18-Aug. 7

3	July 25 Aug. 7 Sept. 2	Aug. 8 Aug. 31	July 18-Aug. 24	Aug. 7-Sept. 6
4	Sept. 2 Oct. 5	Aug 31 Oct. 2	Aug. 24-Sept. 26	Sept. 6-Oct 9.
5	Oct. 5 Nov. 4	Oct. 2 Nov. 3	Sept 26-Nov. 4	Oct. 9-Nov. 2

Table 2. Sampling dates of forage and animal weight dates by pasture period for tame pasture series, 1978-1979.

Pasture Period	Forage Sampling Dates 1978	1979	Animal Weight Dates 1978	1979	Forage Species Utilized
1	May 4	May 14 June 13	April 29-June 6	May 17-June 18	Crested wheatgrass
2	June 26 July 10 July 24	June 11 June 26 July 10 July 25	June 6-July 20	June 18-Aug. 6	Brome-alfalfa
3	July 24 Aug. 7	Aug. 8 Aug. 31	July 20-Aug. 10	Aug. 6-Sept. 1	Sudangrass
4	Aug. 7	Aug. 31	Aug. 10-Sept 22	Sept. 1-Sept. 29	Brome-alfalfa
5	Oct. 6 Nov. 4	Sept 30 Nov. 4	Sept. 22-Nov. 2	Sept. 29-Oct. 31	Russian-wildrye

Vegetation Sampling

Forage plant samples were collected in 1978 and 1979 by clipping plant material to about ground level and placing in paper bags for drying available forage for grazing were determined three times from uncaged samples at early, mid and late grazing season. In 1978 samples were taken on June 13, July 25 and November 4; in 1979 on June 11, June 24 and November 3. A quadrant 30.5 x 122 and 30.5 x 152 cm was used in 1978 and 1979, respectively. Four quadrants were taken randomly in each native and tame grass series pasture. In interseeded pastures, quadrants were laid randomly, but at right angles to the alfalfa rows. Thus, two rows of alfalfa and comparable land area of grass made up these samples. In the native interseeded range and the tame pasture series, alfalfa was separated from the native grass and smooth bromegrass at sampling times. One composite sample, about two meters square, was taken from each pasture at random through the season to determine forage quality of available forage. Sampling dates are shown in Tables 1 and 2. Plant samples were dried at 56°C in forced air ovens, weighed, then ground to pass through a 40-mesh Wiley mill screen. Samples were further ground in a pulvisor mill and stored in coin envelopes.

Botanical composition of native range and native interseeded range were determined in the summer of 1978. A typical point frame with 10 steel rods were used (Levy and Madden 1933). Five transects were taken randomly in each pasture. Within each transect, five quadrants were measured at 2.4, 4.9, 7.3, 9.8 and 12.2 meter intervals. Each steel rod was gently lowered through the point frame and the plant species first touched by the point was recorded. Percent relative density and relative frequency were calculated by the following formulas (Curtis and Cottam 1962):

$$\text{Relative density} = \frac{\text{number of individuals of one species present}}{\text{total number of individuals of all species present}}$$

$$\text{Relative frequency} = \frac{\text{number of occurences of one species present}}{\text{Total number of occurences of all species present}}$$

Forage Quality Determinations

In vitro dry matter digestibility (IVDMD) was determined using duplicate 0.5 gram samples of a modified Tilley and Terry (1963) procedure as described by Wurster (1969). ADF and NDF was determined using single 0.5 gram samples and a modified procedure of Van Soest (1963 a,b). For ADF and NDF, Whatman #54 hardened 12.5 cm filter paper was used in place of Gooch crucibles. For the NDF procedure, the chemicals Ethyl Cellosolve, sodium sulfite and decalin were omitted, as recommended by Britton and Klopfenstein (1979). Although the procedure does not require supplemental heat, we found that chemicals were dissolved into solution more rapidly with low heat than without additional heat. Bulk samples (about one gram from each of the individual pastures within a date and a pasture treatment) were made into a composite sample. Duplicate lignin determinations were made using the Van Soest 1963 method as modified by Goering and Van Soest (1970). Silica, as SiO_2, was determined from duplicate bulk samples. A 0.20 gram sample was burned very slowly so as not to flame. Samples were burned in precleaned platinum crucibles. After burning the forage, about 0.50 gram of sodium carbonate was added, mixed, melted over an open flame and then allowed to fuse for 15 minutes over the flame. Upon cooling, 10.0 ml of plastic distilled-deionized water was dispensed into each crucible and covered with plastic film. These were allowed to stand overnight. The next day the solution in the crucibles were gently wirled and placed into plastic test tubes. An additional 30 ml of like water was used to wash the crucibles clean and to make a stock solution of 40 ml. From the stock solution 0.20 ml was removed and placed into clean plastic test tubes. An additional 19.8 ml of like water was added and the procedure completed as described by Emerick et al. (1963). Crude protein (CP) was calculated by multiplying percent nitrogen by 6.25. A macro-Kjeldahl one gram sample was used to determine percent nitrogen in the sample (Jackson 1958, Brenner 1965). An analysis of variance and simple regression procedure was used to compare differences in forage quality between native and native interseeded range.

Estimations of Dry Matter Intake

Dry matter intake (DMI) in kg/day was estimated using five different methods. In all methods animal body weights were used, and in both Van Soest's methods animal maintenance and gain were taken into consideration. The methods are as follows:

1. Van Soest 1971: net energy (NE) of forage is determined first as NE of lactation ($NE_{lact.}$), then $NE_{lact.}$ is converted into $NE_{maintenance}$ ($NE_{maint.}$) and NE_{gain}. $NE_{maint.}$ and NE_{gain} are expressed as Mcal/kg.

$$NE_{lact.} = 0.01\ TDN\ [2.86 - (35.5/(100\text{-}NDF\%))]$$

$$NE_{gain} = 0.70\ NE_{lact.} - 0.41$$

$$NE_{maint.} = 0.99\ NE_{gain} + 0.69$$

IVDMD was substituted for TDN as recommended by Van Soest (1981).

If animals lost weight the $NE_{maint.}$ of the forage was calculated as:

$$NE_{maint.} = 0.78\ NE_{lact.} + 0.31$$

$NE_{maint.}$ and NE_{gain} for steers were calculated using the formulas of Lofgreen and Garrett (1968). These are:

$NE_{maint.} = 0.077\ W^{0.75}$ where $NE_{maint.}$ is in Mcal/day and W is body weight in kg.

$NE_{gain} = (52.72g + 6.84g^2)\ (W^{0.75})$ where NE_{gain} is in Kcal/day, g is daily gain in kg, and W is body weight in kg.

The kg dry matter needed for maintenance and gain were determined by:

$$\frac{NE_{maint.} \text{ of the animal}}{NE_{maint.} \text{ of the forage}} = \text{kg dry matter for maintenance}$$

$$\frac{NE_{gain} \text{ of the animal}}{NE_{gain} \text{ of the forage}} = \text{kg dry matter for gain}$$

Total dry matter intake = kg dry matter maint. + kg dry matter gain. If steers received corn, then: Total dry matter intake = kg dry matter maint. + kg dry matter gain + kg dry matter corn.

2. Van Soest (1973b): $NE_{maint.}$ and NE_{gain} of forage in Mcal/kg is determined directly by:

$NE_{maint.} = 0.029\ TDN - 0.029$

$NE_{gain} = 0.029\ TDN - 1.01$

IVDMD was substituted again for TDN as recommended by Van Soest (1981). The same procedure in determining dry matter intake was used as in formula 1.

When steers lost weight during the grazing season, it was possible to estimate the reduction in DMI for formulas 1 and 2. Reid and Robb (1971) and Moe and Tyrell (1973) found a 6.3 to 7.9 and 6.0 Mcal loss of energy with each kg loss in body weight of milking cows, respectively. Because values of energy loss per kg of body weight loss have not been reported for beef steers, 6.0 Mcal/kg was considered as a reasonable estimate of energy loss. Thus:

kg body weight loss/day x 6 Mcal/kg = energy loss per day. To calculate DMI formulas 1 and 2:

$NE_{maint.}$ of the animal - energy loss per day/$NE_{maint.}$ of forage = kg DMI

3A. Colburn and Evans 1968: DMI = 0.297 x $^{0.54}$ where x is body weight in kg.

3B. Colburn and Evans 1968: DMI = 0.091 x $^{0.75}$ where x is body weight in kg.

4. Rohweder 1981: this formula has been modified by us to allow for the calculation of kg/day rather than g/kg $^{0.75}$/day.

DMI = (84.7 - 3.69 NDF% + 32.37 NDF%) x (body weight $^{0.75}$)/ 1000.

The computer program to estimate DMI from all five methods is shown in Appendix Table 1. A numeric example for Van Soest's (1971) method 1 DMI is presented in Appendix Table 2.

Prediction of Mean Average Daily Gain

Estimates of DMI were multiplied by either IVDMD or ADF divided by 100 (as digestible dry matter) and coined as "estimated digestible forage intake" (EDFI). EDFI estimates for the Van Soest methods were used in combination with other chemical analyses and regressed against ADG of the steers. The coefficient of determination (R^2) of 90.6 was found with the following formula:

$$ADG = -1.57175 + .29302 \text{ X EDFI} - 0.01467 \text{ X EDFI}^2 + 0.00284 \text{ X EDFI}^3 + 0.064726 \text{ X NDF} - 0.00084 \text{ X NDF}^2.$$

Because of collinearity problems, information from this equation was used to formulate a new substitutive equation for ADG as required in the NE_{gain} for animals as used by Lofgreen and Garrett (1968):

NE_{gain} of animal = $(52.72g + 6.84g^2)$ where g is ADG in Kg.

The new substitutive equation utilized IVDMD/100 (I) and pasture period (PP) by fitting a line for Van Soest's DMI estimates over pasture periods. This line is expressed in terms of I and PP and associated coefficients. The new substitution equation is:

$$NE_{gain} \text{ of animal} = (0.0296 + 0.0308 \times I + 0.0018 \times I^2 + 0.1098 \times I \times PP - 0.0145 \times I \times PP^2 + 0.0213 \times I^2 \times PP^2 + 0.0129 \times I^2 \times PP + 0.0057 \times I^2 \times PP^3 + 0.0004 \times I^2 \times PP^4)$$

Hypothesizing the new NE_{gain} of the animal may predict ADG, we tested it at 1 and 1618 degrees of freedom, finding an $R^2 = 18.1$ and SD of .432. The equation was:

$$ADG = 1.14586 - 0.0191 \times NE_{gain} \text{ of animal.}$$

Prediction of Animal Performance on Pasture

Prediction of mean animal performance on a particular pasture was determined using multiple regression analysis. Mean average daily gain (MADG) in kg/day as the dependent variable and EDFI, NDF, crude protein, 1/lignin, 1/silica and relative feed value (RFV) as the independent variables, were used in the multiple regression analysis. Estimates of DMI were calculated using animal midperiod weights. Midperiod weight is defined as:

Midperiod weight = (Initial weight + Final weight)/2

Midperiod weights were determined for each pasture period for the grazing steers.

DDM (digestible dry matter which is the digestibility of the dry matter) was calculated using ADF and the formula of Rohweder (1981).

$$DDM = 59.0 - 2.26 \text{ ADF\%} + 14.2 \sqrt{\text{ADF\%}}$$

EDFI was determined by the following combinations of estimated dry matter intake and of forage digestibility (either IVDMD or DDM as estimated from ADF):

$$EDFI1 = \text{Van Soest 1971 DMI} \times \frac{IVDMD}{100}$$

$$EDFI2 = \text{Van Soest 1973b DMI} \times \frac{IVDMD}{100}$$

$$EDFI3 = \text{Colburn and Evans 3a DMI} \times \frac{IVDMD}{100}$$

$$EDFI4 = \text{COlburn and Evans 3b DMI} \times \frac{IVDMD}{100}$$

$$EDFI5 = \text{Rohweder DMI} \times \frac{IVDMD}{100}$$

$$EDFI6 = \text{Van Soest 1971 DMI} \times \frac{DDM}{100}$$

$$EDFI7 = \text{Van Soest 1973b DMI} \times \frac{DDM}{100}$$

$$EDFI8 = \text{Colburn and Evans 3a DMI} \times \frac{DDM}{100}$$

$$EDFI9 = \text{Colburn and Evans 3b DMI} \times \frac{DDM}{100}$$

$$EDFI10 = \text{Rohweder DMI} \times \frac{DDM}{100}$$

RFV was calculated by:

$$RFV = DDM \times DMI/100 \times 1.45$$

where: DDM is same as above

$$DMI = 84.7 - 3.69\ NDF\% + 32.37\ \sqrt{NDF\%}$$

Climatic Data

Average maximum, minimum and monthly average temperatures along with total precipitation and departures from normal for 1977 to 1979 from Faulkton, South Dakota are given on Appendix Tables 3 to 5, respectively.

RESULTS AND DISCUSSION

I. Botanical Composition Of Native And Interseeded Ranges

The botanical composition of native and interseeded ranges were determined in 1978 at the mid-point of the grazing study and three years after establishment of 'Travois' alfalfa. The data collected provided estimates of relative density, which is an estimate of the number of plant species within the pasture, and relative frequency, the distribution of a given species within the pasture. Percent relative density on interseeded ranges indicated that alfalfa at 30.2 percent was the most abundant species, followed by Kentucky bluegrass and western wheatgrass, Table 3. Kentucky bluegrass and needle-and-thread were the most important species in the native range, followed by western wheatgrass. When plant densities of interseeded range with alfalfa and interseeded range without the alfalfa component were compared, the sod-forming grasses, such as Kentucky bluegrass and western wheatgrass, increased in importance. Bunchgrasses, such as needle-and-thread and green needlegrass, were more abundant in the native range than in the interseeded range with alfalfa. The South Dakota interseeding technique, with its relatively wide furrows, appears to enhance sod-forming grasses and slightly suppress bunchgrass species.

The percent relative frequency or evenness of distribution of a species within the plant community are present in Table 3. In the interseeded range, alfalfa had the highest relative frequency for a given species, 18.9 percent, indicating a fairly even distribution of alfalfa in the pasture. Alfalfa was followed by sod-forming, then bunchgrasses in their evenness of distribution. In the native range, Kentucky bluegrass, needle-and-thread, and western wheatgrass all appear to be equally distributed. These data demonstrate a stable mixed sod and bunchgrass plant community in the native and interseeded ranges. Distribution of grasses in the native and interseeded does not appear to be influenced by the association of alfalfa.

Table 3. Percent relative density and frequency of major plant species in native and interseeded ranges, 1978.

	Native		Interseeded With Alfalfa		Interseeded Without Alfalfa	
Plant Species	Mean	S.E.[1]	Mean	S.E.	Mean	S.E.
	---------- Percent Relative Density ----------					
Alfalfa	--	--	30.2	3.0	--	--
Western Wheatgrass	17.1	1.0	11.5	1.1	16.4	1.3
Green needlegrass	9.0	1.4	4.0	.6	5.5	.9
Needle-and-thread	20.0	2.4	8.2	.9	11.1	1.4
Kentucky bluegrass	20.8	2.0	17.5	1.8	24.8	2.3
Other tame grasses	--	--	6.2	2.1	9.9	4.0
Other species[2]	33.0	2.7	22.4	2.7	31.4	2.9
	-------- Percent Relative Frequency --------					
Alfalfa	--	--	18.9	1.6	--	--
Western Wheatgrass	15.2	8.5	12.3	.6	15.2	.8
Green needlegrass	9.4	1.0	5.6	.7	6.8	.9
Needle-and-thread	13.7	1.0	9.9	1.0	12.2	1.4
Kentucky bluegrass	15.3	.9	15.7	.9	19.8	1.3
Other tame grasses	--	--	4.4	1.5	5.7	2.1
Other species[2]	46.7	2.2	34.0	2.4	40.2	3.2

[1]Standard error of the mean

[2]Includes such species as bluegrama, prairie junegrass, sedges, forbs and others. Each contribution $\leq$ 1% of the total.

II. Available Forage Dry Matter Yields

The available forage for grazing, in kg/ha, for the 1978 and 1979 grazing season at the early, middle and end of the grazing season for three pasture systems are presented in Table 4. Substantial climatic differences occurred between the growing seasons; the spring of 1978 was cool and wet with adequate moisture extending into the summer and early fall grazing. Forage availability was lower in 1979 due to a cool, dry spring. Moisture arrived in July, and was generally adequate for the remainder of the season.

Interseeded ranges had 93 and 50 percent more available forage in the early spring than the native range for 1978 and 1979, respectively. The alfalfa component in the interseeded pastures in 1978 and 1979 was 36 and 66 percent, respectively. Alfalfa production was essentially the same in both years, however native grass production was suppressed in 1979. Forage availability in the brome-alfalfa pasture was almost twice as much as in the native range.

The alfalfa component in the interseeded range was still large at mid-season, indicating that animals were not selectively grazing out the alfalfa. In the brome-alfalfa pastures the alfalfa component had dramatically decreased, indicating the grazing steers were selecting alfalfa over the bromegrass. Sudangrass, a warm-season annual, was sampled before grazing and was considerably higher in relative forage availability than the native range. In a good year, as in 1978, sudangrass had about the same forage availability as interseeded and brome-alfalfa. In a drier year, such as 1979, sudangrass availability were much greater than the other pasture treatments. In the interseeded range, alfalfa was still available for grazing in early September of both years, but had been grazed out by the October and November samplings. The alfalfa plants were still present, but they were not making any contribution to the available forage.

At the end of the grazing season the tame pasture component, Russian wildrye, had less forage remaining than either the native or interseeded ranges. Russian wildrye was grazed only in the late fall and at a very heavy stocking rate so as to remove 90-95 percent of the top growth. The interseeded range had about 35 percent more forage remaining than the native range at the end of the 1978 grazing season, despite higher stocking rates. The interseeded range had only 62 percent as much forage as the native range in 1979 due to lower forage production.

Table 4. Available forage kg/ha and percent relative forage availability of pasture systems at early, mid and end of grazing system, 1978-1979.

Pasture System	Forage Yield Dry Weight 1978	Forage Yield Dry Weight 1979	Percent Forage Availability 1978	Percent Forage Availability 1979	Percent Alfalfa 1978	Percent Alfalfa 1979
	------------	------------	June 14	------------	------------	------------
Native	1623	1447	100	100	--	--
Interseeded	3132	2177	193	150	36	66
Brome-alfalfa	4232	2578	261	178	32	33
	------------	------------	July 25	------------	------------	------------
Native	2866	1564	100	100	--	--
Interseeded	3732	2109	131	135	34	63
Brome-alfalfa	3860	2462	135	157	19	12
Sudangrass	3908	4247	136	273	--	--
	------------	------------	November 3	------------	------------	------------
Native	1285	1542	100	100	--	--
Interseeded	1740	953	135	62	--	--
Russian wildrye	--	701	--	45	--	--

III. Forage Quality Comparisons

Several analytical methods were used to estimate forage quality on the different pasture systems. In the native and interseeded ranges both short- and long-season comparisons were made. The analysis of variance for short- and long-season forage quality comparisons are presented in Appendix Tables 6-17. Quasi F Test and appropriate degrees of freedom are presented in Appendix Tables 18 and 19. Short season analyses are from June 14 to September 1. These are further divided into native and interseeded range and interseeded range without alfalfa. These analyses depict the influence of alfalfa on the quality of forage available for grazing and they document changes in the native forage grown in association with alfalfa. After the September sampling, alfalfa could no longer be detected by sampling. Alfalfa was present as small regrowth tillers at ground level and not available for grazing.

Long-season analyses were from June 14 to November 4 and they are divided into native and interseeded ranges. Forage quality differences on the available forage for the two pasture systems are documented throughout the grazing season.

Digestibility as measured by IVDMD and ADF decline as the season progressed on both native and interseeded pastures. Significant differences in IVDMD occurred between years, year X pasture type and sampling dates were found. IVDMD in 1979, as compared to 1978, was higher early in the season but lower during the latter part of the season (Table 5). This is in part due to the much greater IVDMD of the interseeded in 1979 when greater than 60 percent of the dry matter yield was from alfalfa. Interseeding in 1978 increased IVDMD over the native range on the average of 5 percentage units throughout the grazing season, (Table 6). For season-long, IVDMD decreased an average of 0.14 percent per day. IVDMD of the native and interseeded range minus the alfalfa were essentially the same throughout the grazing season.

ADF has been shown to be correlated with dry matter digestibility (Van Soest 1964, 1965, 1967). ADF is the measure of the plant's cellulose and lignin content, along with some plant cell wall protein and minerals. ADF for both the short- and long-season grazing are presented in Tables 7 and 8. Only slight differences between pasture types were found in 1978 (Table 7). However, ADF estimates were much lower in 1979 on the interseeded range, again indicating the presence of large amounts of alfalfa as compared to the native grass. After the September sampling date, little differences were found for the native or interseeded range in either year (Table 8).

Table 5. Percent IVDMD of native, interseeded and interseeded range without the alfalfa component, short-season, 1978-1979.

Year	Pasture System	Sampling Dates June 14	June 26	July 10	July 25	Aug. 7	Sept. 1
1978	Native	58.0	52.7	50.1	48.2	45.7	44.0
	Interseeded	63.3	58.8	55.2	53.3	51.4	48.4
	Interseeded w/o alfalfa	58.4	51.5	48.6	47.0	44.8	42.5
1979	Native	53.4	52.0	49.0	46.1	44.1	41.9
	Interseeded	70.0	65.1	59.3	55.8	51.0	47.2
	Interseeded w/o alfalfa	60.1	57.2	49.5	46.6	44.0	37.7

	1978	59.9	54.3	51.3	49.5	47.3	44.9
	1979	61.2	58.1	52.6	49.5	46.4	42.2
	Mean	60.5	56.2	52.0	49.5	46.8	43.6

CV = 6.73

Table 6. Percent IVDMD of native and interseeded ranges, long-season, 1978-1979.

Year	Pasture System	Sampling Dates June 14	June 26	July 10	July 25	Aug 7	Sept 1	Oct 1	Nov 4
1978	Native	58.0	52.7	50.1	48.2	45.7	44.0	41.8	38.5
	Interseeded	63.3	58.8	55.2	53.3	51.4	48.4	46.7	44.8
1979	Native	53.4	52.0	49.0	46.1	44.1	41.9	40.2	35.1
	Interseeded	70.0	65.1	59.3	55.8	51.0	47.2	44.5	38.9
	1978	60.6	55.8	52.6	50.8	48.6	46.2	44.2	41.6
	1979	61.7	58.5	54.2	50.9	47.6	44.6	42.3	37.0
	Mean	61.2	57.1	53.4	50.8	48.1	45.2	43.3	39.3

CV = 6.60

Table 7. Percent ADF of native, interseeded and interseeded range without the alfalfa component, short-season, 1978-1979.

Year	Pasture System	Sampling Dates June 14	June 26	July 10	July 25	Aug 7	Sept 1	Year Pasture System
1978	Native	34.0	37.2	38.4	39.6	41.4	42.4	38.7
	Interseeded	35.6	37.6	38.2	38.7	39.7	42.9	38.8
	Interseeded w/o alfalfa	37.9	40.2	41.6	42.0	43.4	46.0	41.8
1979	Native	35.8	37.2	38.7	39.3	40.3	40.6	38.6
	Interseeded	26.8	29.2	31.8	33.4	36.7	39.1	32.8
	Interseeded w/o alfalfa	34.0	35.3	37.4	38.8	40.0	43.4	38.2
	Mean	34.1	36.1	37.7	38.6	40.2	42.4	

CV = 6.53

Table 8. Percent ADF of native and interseeded ranges, long-season 1978-1979.

Year	Pasture System	June 14	June 26	July 10	July 25	Aug 7	Sept 1	Oct 1	Nov 4
1978	Native	34.3	37.2	38.4	39.6	41.4	42.4	44.0	45.1
	Interseeded	35.6	37.6	38.2	38.7	39.7	42.9	46.3	47.8
1979	Native	35.8	37.2	38.7	39.3	40.3	40.6	42.2	45.5
	Interseeded	26.8	29.2	31.8	33.4	36.7	39.1	42.5	46.8
	1978	35.0	37.4	38.3	39.2	40.6	42.3	45.2	46.4
	1979	31.3	33.2	35.3	36.3	38.5	39.9	42.3	46.1
	Mean	33.1	35.3	36.8	37.7	39.5	41.2	43.8	46.3

CV = 5.57

NDF or total CWC for the native and interseeded ranges for short- and long-season analysis are shown in Tables 9 and 10. The interseeded range forage in the early spring contained about 50 percent cell walls indicating a high amount of readily digestible cell contents. NDF on interseeded ranges increased with advanced maturity as did the native and native grasses within the interseeded range. At the end of the short-season, alfalfa lowered CWC of interseeded about 6 percentage units when compared to the other pasture treatments (Table 9). However, in the long-season analysis these differences were not detected in either the October or November samplings (Table 10). Years were different for long-season analysis with 1979 generally having lower total CWC. Since legumes are generally lower than grasses in CWC (Van Soest 1965) the alfalfa lowers the total CWC of the interseeded pastures. NDF is also an indication of forage bulkiness; the less bulky forage contain more available nutrients. On season-long analysis, NDF increased an average of 0.12 percentage units per day for all treatments (Table 10).

Table 9. Percent NDF of native, interseeded and interseeded range without the alfalfa component, short-season, 1978-1979.

Year	Pasture System	Sampling Dates						Year Pasture System
		June 14	June 26	July 10	July 25	Aug 7	Sept 1	
1978	Native	53.7	58.6	62.4	63.9	65.0	66.0	61.7
	Interseeded	49.1	51.7	53.3	55.3	59.8	63.8	55.5
	Interseeded w/o alfalfa	55.2	59.2	61.2	63.1	65.1	67.5	61.9
1979	Native	59.6	63.1	64.0	64.9	66.1	66.5	64.0
	Interseeded	42.0	43.7	47.8	49.9	57.1	60.0	50.1
	Interseeded w/o alfalfa	56.4	60.3	62.1	64.3	67.2	68.1	63.1
	Mean	52.7	56.1	58.5	60.2	63.4	65.3	

CV = 4.48

Table 10. Percent NDF of native and interseeded ranges, long-season, 1978-1979.

Year	Pasture System	Sampling Dates							
		June 14	June 26	July 10	July 25	Aug 7	Sept 1	Oct 1	Nov 4
1978	Native	53.7	58.6	62.4	63.9	65.0	66.0	66.7	68.7
	Interseeded	49.1	51.7	53.3	55.3	59.8	63.8	67.6	69.8
1979	Native	59.6	63.1	64.0	64.9	66.1	66.5	67.1	69.8
	Interseeded	42.0	43.7	47.8	49.9	57.1	60.0	64.0	70.8
	1978	51.4	55.2	57.8	59.6	62.4	64.5	67.2	69.3
	1979	50.8	53.4	55.9	57.4	61.6	63.2	65.8	70.3
	Native	56.6	60.9	63.2	64.4	65.5	66.3	66.9	69.2
	Interseeded	45.6	47.7	50.5	52.6	58.5	61.9	65.8	70.3
	Mean	51.1	54.8	56.9	58.5	62.0	64.1	66.4	69.8

CV = 4.17

Crude protein (CP) was increased by interseeding when alfalfa was available to the grazing animal, essentially during the short-season (Table 11). Interseeding compared to native increased CP by about 4 percentage units early in the grazing season. In October and November the CP content of the interseeded and native ranges were essentially the same. Yearly variations occurred in CP content with 1979 CP much greater in both the short- and long-season comparisons (Table 12). The suppressed grass growth due to the dry 1979 spring probably was the major contributing factor and increased CP content of herbage from 8.6 in 1978 to 10.2 in 1979. CP levels fell below those recommended for growing cattle during the October and November months and a protein supplement at this time could be beneficial. CP declined an average of 0.05 percentage units per day over the full grazing season.

Table 11. Percent CP of native, interseeded and interseeded range without the alfalfa component, short-season, 1978-1979.

Pasture System	Sampling Dates June 14	June 26	July 10	July 25	Aug. 7	Sept. 1	Mean
Native	10.3	9.7	9.1	8.3	8.1	7.6	8.8
Interseeded	15.2	14.4	12.3	11.3	10.8	9.4	12.2
Interseeded w/o alfalfa	12.3	10.2	9.2	9.1	8.4	7.9	9.5
1978	11.2	10.0	9.7	9.2	8.4	7.4	9.3
1979	14.0	12.8	10.7	9.9	9.8	9.2	11.1
Mean	12.6	11.4	10.2	9.6	9.1	8.3	

CV = 10.51

Table 12. Percent CP of native and interseeded ranges, long-season, 1978-1979.

Year	Pasture System	Sampling Dates June 14	June 26	July 10	July 25	Aug 7	Sept 1	Oct 1	Nov 4
1978	Native	9.5	8.8	8.9	9.4	7.4	7.0	5.8	4.8
	Interseeded	13.3	12.3	11.5	10.8	10.1	8.2	5.7	4.7
1979	Native	11.0	10.6	9.2	8.2	8.8	8.2	6.9	6.3
	Interseeded	17.2	16.4	13.0	11.8	11.5	10.7	7.6	6.5
	1978	11.4	10.5	10.2	9.6	8.7	7.6	5.7	4.8
	1979	14.1	13.5	11.1	10.0	10.2	9.4	7.3	6.4
	Native	10.3	9.7	9.1	8.3	8.1	7.6	6.3	5.5
	Interseeded	15.2	14.4	12.3	11.3	10.8	9.4	6.7	5.6
	Mean	12.7	12.0	10.7	9.8	9.4	8.5	6.5	5.6

CV = 11.00

Significant differences were found in lignin percentages in both short- and long-season grazing periods (Tables 13 and 14). Lignin increases with advancement of maturity in a step-like pattern; it increases, then levels off followed by another increase and leveling off period. Increase in lignin content is often due to increased plant stress and these data suggest that lignin is not laid down continuously, but rather in a step-like pattern. The pattern appears to continue until the end of the grazing season. Legumes are often higher in lignin than grasses; thus the higher lignin content of interseeded ranges is expected. Lignin content declines in the interseeded range when alfalfa is not present during the October and November sampling dates (Table 14). These data support those of Campbell and Dotzenko (1974) and Thompson and Dotzenko (1977) that lignin, the most indigestible portion of the cell wall, increases with the season.

Table 13. Percent lignin of short-season forage, 1978-1979.

	Sampling Dates					
	June 14	June 26	July 10	July 25	Aug. 7	Sept. 1
1978	3.8	4.8	4.8	5.4	5.3	5.5
1979	4.0	4.2	4.4	5.2	5.2	6.0
Mean	3.9	4.5	4.6	5.3	5.2	5.8

Table 14. Percent lignin of native and interseeded ranges, long-season, 1978-1979.

Pasture	Sampling Date							
System	June 14	June 26	July 10	July 25	Aug 7	Sept 1	Oct 1	Nov 4
Native	3.5	3.7	3.9	4.5	4.6	4.6	4.8	5.3
Interseeded	4.4	5.4	5.6	6.3	6.2	7.2	6.8	6.1
1978	3.9	4.8	4.7	5.3	5.3	5.4	5.2	5.4
1979	4.0	4.3	4.7	5.5	5.4	6.3	6.4	6.0

CV = 6.42

Silica is present in the cell walls of grasses with little or no accumulation in the walls of legumes. Native range and native grasses in the interseeded range have a greater silica content than the interseeded range with alfalfa (Tables 15 and 16). Silica appears to accumulate more in native range than grasses associated with alfalfa. Interseeded samples were hand separated in the pasture and perhaps the native grasses grown in association with the alfalfa accumulated less silica. There is no evidence of the phenomenon in the literature, however. These data support that of Campbell and Dotzenko (1975) and Thompson and Dotzenko (1977) that grasses accumulate silica under pasture conditions.

Table 15. Percent silica of native, interseeded and interseeded range without the alfalfa component, short-season, 1978-1979.

Year	Pasture System	Sampling Dates June 14	June 26	July 10	July 25	Aug 7	Sept 1	Year Pasture System
1978	Native	4.4	4.4	5.2	6.0	6.0	7.0	5.5
	Interseeded	2.4	2.9	3.1	3.2	4.6	5.2	3.6
	Interseeded w/o alfalfa	3.8	4.0	4.4	5.4	5.8	6.2	4.9
1979	Native	5.5	5.4	5.6	5.8	6.8	7.3	6.2
	Interseeded	1.6	1.8	2.2	2.2	3.9	3.4	2.5
	Interseeded w/o alfalfa	3.0	4.5	4.6	5.2	5.8	6.6	5.0
	1978	3.6	3.8	4.3	4.8	5.5	6.1	
	1979	3.4	3.9	4.1	4.4	5.5	5.8	
	Mean	3.5	3.8	4.2	4.6	5.5	5.9	

CV = 2.50

Table 16. Percent silica of native and interseeded ranges, long-season, 1978-1979.

Pasture System	Sampling Dates June 14	June 26	July 10	July 25	Aug 7	Sept 1	Oct 1	Nov 4	Year Pasture System
1978									
Native	4.4	4.4	5.2	6.0	6.0	7.0	7.2	7.6	6.0
Interseeded	2.4	2.9	3.1	3.2	4.6	5.2	5.4	6.0	4.1
1979									
Native	5.5	5.4	5.6	5.8	6.8	7.3	8.4	8.7	6.7
Interseeded	1.6	1.8	2.2	2.2	3.9	3.4	5.1	6.6	3.4
1978	3.4	3.6	4.2	4.6	5.4	6.1	6.3	6.8	
1979	3.6	3.6	3.9	4.0	5.3	5.3	6.8	7.6	

CV = 2.59

Forage quality of the tame grasses by pasture component is presented in Table 17. Pasture quality was high in the crested wheatgrass in the early spring and declined as the season advanced. However, IVDMD was maintained at a 60 percent level for the crested wheatgrass, early brome-alfalfa and sudangrass pasture. One objective of the tame grass series was to provide the grazing steers with a high quality forage for as much of the grazing season as possible. After evaluating the different chemical determinations of the tame grasses, forage quality was found to be excellent for the crested wheatgrass through sudangrass pasture. Early fall grazing of brome-alfalfa and late fall grazing of Russian wildrye provided the poorest forage quality in the tame grass series.

IVDMD was higher on the tame grasses as compared to native range in all pasture components, except Russian wildrye, where it equaled native range. ADF value of tame pastures was lower in the early spring and about equal to native and interseeded in the fall. Crude protein was higher in the tame grasses than the native range and similar to interseeded range. Percent lignin was highest in interseeded range, intermediate in native and lowest in tame series. An increase in lignin was found with the brome-alfalfa pastures due to the alfalfa, but somewhat less than the interseeded range. This is probably because less alfalfa was found in the brome-alfalfa than the interseeded pasture (Table 4).

Several trends were found for all pasture systems when evaluated by forage quality. IVDMD and CP decreased with advance of the season, however, not as rapidly in the tame grasses as the native or interseeded ranges. ADF, NDF, lignin and silica all increased with maturity although not at the same rates. These data support the forage quality data in the literature as reported by Newell and Moline (1978), Campbell and Dotzenko (1975) and Thompson and Dotzenko (1977). Forage quality changes associated with interseeding appear to come from the addition of an alfalfa component rather than changes in the forage grown in association with the alfalfa.

Table 17. Forage quality of different pasture components of a tame pasture series during the 1978 and 1979 grazing season. Quality determinants in percent are IVDMD, ADF, NDF, CP, lignin and silica, 1978-1979.

	Pasture Component				
Year	Crested wheatgrass	Brome-alfalfa	Sudan-grass	Brome-alfalfa	Russian wildrye
			IVDMD		
1978	75.0	59.5	65.0	54.5	43.2
1979	55.2	60.6	58.8	51.0	44.9
Mean	61.8	60.0	61.9	52.7	44.1
			ADF		
1978	22.0	36.0	32.5	38.6	49.1
1979	31.0	33.6	37.7	40.0	39.7
Mean	27.7	34.6	35.1	39.3	44.4
			NDF		
1978	43.2	53.5	57.5	59.0	72.2
1979	55.8	56.0	60.1	63.5	68.4
Mean	51.9	54.9	58.8	61.3	70.3
			CP		
1978	23.0	9.6	16.0	8.0	5.6
1979	14.1	10.4	9.7	7.8	9.3
Mean	17.1	10.0	12.9	7.9	7.5
			Lignin		
1978	2.6	4.2	3.4	4.7	7.0
1979	3.9	3.8	3.0	4.8	5.5
Mean	3.2	4.0	3.2	4.8	6.2
			Silica		
1978	3.4	4.1	3.5	5.4	8.2
1979	4.6	4.0	3.9	5.4	5.7
Mean	4.0	4.1	3.7	5.4	7.0

IV. Estimations of Dry Matter Intake by Grazing Steers

Dry matter intake (DMI) of grazing steers were estimated by five different methods rather than using the standard method of determining fecal output in a 24-hour period with a collection harness and bag and forage digestibility. These methods are: (1) Van Soest (1971), (2) Van Soest (1973b), (3A) Colburn and Evans (1968), (3B) Colburn and Evans (1968), and (4) Rohweder (1981). Analysis of variance for DMI estimates are presented in Appendix Tables 20-24. Quasi F Tests and appropriate degrees of freedom are presented in Appendix Tables 25 and 26.

Van Soest's (1971) method 1 for estimating DMI requires IVDMD and NDF as forage chemical analysis, an estimate of body weight and the average daily gain of the animal. DMI estimates by method 1 are presented in Table 18. Differences were found for year X pasture system X pasture period, year X pasture period, and pasture periods. DMI estimates were lower in 1978 than 1979 suggesting that forage quality in 1978 was somewhat better and that the animals needed to consume less. When DMI estimates for pasture systems within each year were compared, native range was consistently higher than interseeded or tame in all pasture periods except period 5, 1979, where the Russian wildrye pasture had a much higher estimated intake. For the two year mean, a pattern of increasing DMI occurs between periods 1 and 4 followed by a sharp decline in period 5. This pattern was also evident for several pasture systems within the years. DMI increased as the season progressed reflecting a decline in forage quality and increase animal weight. In period 5 the decrease in DMI reflects the low forage quality. A mean of 17.23 kg/day and 32.18 percent coefficient of variation (CV) was found for Van Soest 1971, method 1.

Table 18. Estimated dry matter intake, kg/day, for three pasture systems and five pasture periods. Based on Van Soest (1971) Method 1.

Year	Pasture Management Systems	Pasture Period 1	2	3	4	5
1978	Native	9.43	14.18	17.48	24.00	20.60
	Interseeded	8.79	11.65	13.72	15.73	18.89
	Tame	7.96	12.85	10.70	11.41	20.14
1979	Native	18.17	25.08	37.40	30.04	12.76
	Interseeded	10.79	17.71	23.26	24.78	7.59
	Tame	13.99	13.24	14.30	23.16	27.11
	Year					
	1978	8.73	12.89	13.96	17.00	19.90
	1979	14.32	18.67	24.99	25.99	15.82
	Mean	11.52	15.78	19.48	21.52	17.85

Van Soest's 1973b, Method 2 for estimating DMI requires IVDMD as the only forage quality measurement, estimated animal body weight and average daily gain of the grazing animal. Estimates of DMI for Method 2 are shown in Table 19. Significant year X pasture period and year X pasture system X pasture periods interactions were found. The estimated DMI determined from all pasture periods, except period 5, was substantially lower in 1978 than 1979. DMI increased from one period to the next throughout 1978 and 1979 until period 5 in 1979 when DMI decreased. This decrease could again be attributed to forage quality decline in the late fall.

Percent grain X pasture period interactions were also significant. DMI increased as grain energy (GNE) supplementation increased throughout the grazing season in both years. An increased DMI with GNE showed that feeding corn on pasture did not suppress pasture intake.

DMI increased for all pasture systems as the season advanced in 1978. This trend was evident for tame in 1979, but in period 5, for both native and interseeded ranges, DMI declined sharply.

In order to obtain the same animal performance, cattle grazing native range had to have a 44 and 58 percent greater DMI than those on interseeded range and tame pasture grasses, respectively. Overall, DMI estimates for Van Soest's 1973b method 2 were 14.68 kg/day and 37.93 percent CV.

Table 19. Estimated dry matter intake, kg/day, for three pasture systems, three grain levels, five pasture periods in 1978 and 1979. Based on Van Soest (1973b) Method 2.

		Pasture Period					Mean
Year	Pasture System	1	2	3	4	5	Pasture System
1978	Native	7.83	11.67	14.88	22.05	24.75	18.88
	Interseeded	7.31	9.75	11.61	12.47	13.93	13.07
	Tame	6.38	10.51	8.08	9.37	13.09	11.96
1979	Native	14.47	20.72	31.72	27.86	12.89	
	Interseeded	9.15	15.98	21.06	22.31	7.09	
	Tame	11.66	10.42	10.88	18.44	20.79	
	Year						
	1978	7.17	10.64	11.53	14.63	17.25	
	1979	11.76	15.71	21.22	22.87	13.59	
	Grain Level						
	0	8.62	12.53	14.79	17.91	11.76	
	0.5	9.95	13.04	16.36	17.67	12.40	
	1.0	9.84	13.96	17.97	20.67	22.11	

Differences in estimates of DMI using Colburn and Evans method 3A were found for year, year X pasture period, year X pasture system X pasture period, year X GNE, year X GNE X pasture period, pasture system X GNE and pasture periods (Tables 20, 21 and 22). Colburn and Evans method 3A estimates DMI by using the body weight of the grazing animal to the 0.54 power. Neither forage quality measurements nor animal daily gains are required for method 3A.

Estimates of DMI were higher in 1979 that 1978 due to larger grazing steers. DMI increased slightly from one pasture period to the next, but not to the degree as found with Van Soest's methods 1 and 2. Increases are based on animal weights over time. Percent GNE varied with pasture periods (Table 21). Generally, DMI estimates increased more rapidly within the season and at a greater level with corresponding increases in corn percentages. The same pattern was found when comparing year X GNE X pasture systems, with greater increases occurring in 1979 than 1978. These data collectively establish more rapid increases in estimated DMI with increasing GNE for method 3A.

Pasture systems and pasture means had varied increases in GNE (Table 22). Greater DMI increases were found from 0.0 to 0.5 percent than from 0.5 to 1.0 percent. Pasture systems varied with pasture period, with period 1 interseeded and tame DMI estimates being similar (7.8 kg/day), whereas in the other pasture period tame grasses were consistently higher. This trend appears to follow when comparing pasture systems X pasture periods X GNE (Table 22). The overall DMI mean and CV for method 3A is 8.71 kg/day and 5.98 percent, respectively.

Table 20. Estimated dry matter intakes, kg/day, for three pasture systems, five pasture periods in 1978 and 1979. Based on Colburn and Evans (1968) Method 3A.

Year	Pasture System	Pasture Period 1	2	3	4	5	Year
1978	Native	7.60	7.93	8.45	8.82	9.11	8.50
	Interseeded	7.59	7.95	8.49	8.83	9.10	
	Tame	7.76	8.38	8.91	9.18	9.46	
1979	Native	7.95	8.46	8.84	9.32	9.52	8.92
	Interseeded	8.11	8.61	9.00	9.49	9.75	
	Tame	7.85	8.47	9.10	9.48	9.87	
	Year						
	1978	7.65	8.09	8.62	8.94	9.22	
	1979	7.97	8.52	8.98	9.43	9.71	
	Mean	7.81	8.30	8.80	9.19	9.47	

Table 21. Estimated dry matter intake, kg/day for three grain levels and five pasture periods in 1978 and 1979. Based on Colburn and Evans' (1968) Method 3A.

Year	Grain Level	Pasture Period 1	2	3	4	5	Year X Grain Level
1978	0.0	6.30	6.62	6.94	7.14	7.31	6.86
	0.5	7.66	8.10	8.63	8.98	9.24	8.52
	1.0	8.99	9.54	10.29	10.71	11.12	10.13
1979	0.0	6.50	6.84	7.12	7.38	7.48	7.06
	0.5	7.98	8.51	8.98	9.44	9.71	8.92
	1.0	9.44	10.20	10.84	11.48	11.95	10.78
	0.0	6.40	6.73	7.03	7.26	7.39	
	0.5	7.82	8.31	8.80	9.21	9.48	
	1.0	9.22	9.87	10.57	11.10	11.53	

Table 22. Estimated dry matter intake, kg/day, for three pasture systems at three grain levels and five pasture period. Based on Colburn and Evans (1968) Method 3A.

Pasture Period	Pasture System	Grain Level 0.0	Grain Level 0.5	Grain Level 1.0	Mean Pasture System X Pasture Period
1	Native	6.42	7.83	9.15	7.78
	Interseeded	6.54	7.94	9.33	7.85
	Tame	6.47	7.84	9.34	7.81
2	Native	6.76	8.46	9.74	8.20
	Interseeded	6.98	8.50	10.02	8.28
	Tame	7.09	8.64	10.35	8.43
3	Native	7.14	9.07	10.70	8.65
	Interseeded	7.44	9.10	10.78	8.75
	Tame	7.56	9.36	11.38	9.01
4	Native	7.49	9.63	11.41	9.07
	Interseeded	7.81	9.66	11.48	9.16
	Tame	7.84	9.83	11.93	9.33
5	Native	7.69	9.89	11.89	9.31
	Interseeded	7.97	10.00	11.97	9.42
	Tame	8.08	10.26	12.56	9.66
	Native	6.83	8.66	10.31	
	Interseeded	7.00	8.70	10.37	
	Tame	7.04	8.80	10.69	
	Mean	6.96	8.72	10.46	

Colburn and Evans (1968) method 3B for estimating DMI uses only body weight to the 0.75 power. Estimated DMI increased from period to period as the season progressed in both 1978 and 1979 (Table 23). Pasture systems varied with GNE levels for estimating DMI (Tables 24 and 25). DMI trends for both method 3A and 3B show the greatest increase in DMI from zero to 0.5 percent grain supplementation rather than from 0.5 to 1.0 percent. DMI was generally higher in 1979 in all pasture systems and the intake differences between pastures was minor.

No decline in DMI due to the advance of the season or changes in forage quality were detected in either method 3A or 3B. The important factor in estimating DMI by method 3B was animal size and pasture period. Overall, a mean of 9.06 kg/day and a CV of 7.43 percent were found using method 3B to estimate DMI.

Table 23. Estimated dry matter intake, kg/day, for three pasture systems at five pasture periods. Based on Colburn and Evans (1968) Method 3B.

		Pasture Periods				
Year	Pasture System	1	2	3	4	5
1978	Native	7.61	8.05	8.72	9.19	9.57
	Interseeded	7.59	8.08	8.77	9.21	9.56
	Tame	7.83	8.64	9.31	9.67	10.03
1979	Native	8.08	8.72	9.23	9.84	10.08
	Interseeded	8.28	8.92	9.45	10.09	10.40
	Tame	7.94	8.75	9.56	10.06	10.57
	Year					
	1978	7.68	8.26	8.93	9.36	9.72
	1979	8.10	8.80	9.41	10.00	10.35
	Mean	7.89	8.53	9.17	9.68	10.04

Table 24. Estimated dry matter intake, kg/day, for three pasture systems at three grain levels. Based on Colburn and Evans' (1968) Method 3B.

	Grain Level		
Pasture System	0.0	0.5	1.0
Native	7.10	8.99	10.63
Interseeded	7.35	9.04	10.72
Tame	7.41	9.19	11.11
Year			
1978	7.14	8.81	10.41
1979	7.43	9.34	11.22
Mean	7.28	9.07	10.82

Table 25. Estimated dry matter intake, kg/day, for three pasture systems at three grain levels and five pasture periods. Based on Colburn and Evans (1968) Method 3B.

Pasture Period	Grain Level	Pasture System			Mean Pasture Period X Grain
		Native	Interseeded	Tame	
1	0.0	6.42	6.54	6.48	6.48
	0.5	7.91	7.94	7.84	7.90
	1.0	9.21	9.33	9.34	9.25
2	0.0	6.76	6.98	7.09	6.94
	0.5	8.46	8.50	8.64	8.53
	1.0	9.94	10.02	10.35	10.10
3	0.0	7.14	7.44	7.56	7.38
	0.5	9.07	9.10	9.36	9.18
	1.0	10.70	10.78	11.38	10.95
4	0.0	7.49	7.81	7.84	7.71
	0.5	9.63	9.66	9.83	9.71
	1.0	11.41	11.48	11.93	11.61
5	0.0	7.69	7.97	8.08	7.91
	0.5	9.89	10.00	10.26	10.05
	1.0	11.89	11.97	12.56	12.14
	Mean	8.91	9.04	9.24	

DMI estimates by the Rohweder (1981) method 4 are presented in Tables 26 and 27. Method 4 utilizes NDF as a forage quality measurement and the weight of the animals to the 0.75 power. DMI increased as the season progressed up to period 4, then decreased in period 5 in both 1978 and 1979. This is the same trend that was found for both the Van Soest methods because changes in forage quality are used to estimate DMI. Native range had the lowest DMI, averaging 5 and 13 percent less than interseeded and tame grasses, respectively. This is opposite to the DMI intake estimates from methods 1 and 2 where native range was estimated to have a greater intake than interseeded or tame grasses.

Van Soest (1965) has shown that NDF is an estimate of dry matter intake with a negative correlation of 0.7. Although Rohweder's method estimates DMI higher than the Colburn and Evans methods, all three appear to be much lower than methods 1 and 2 of Van Soest. Overall means of method 4 DMI estimates are 20.78 kg/day and CV of 7.39 percent.

Table 26. Estimated dry matter intake, kg/day, for three pasture systems, five pasture periods in 1978 and 1979. Based on Rohweder (1981) Method 4.

		Pasture Period					Mean
Year	Pasture System	1	2	3	4	5	Pasture System
1978	Native	9.84	9.30	9.89	10.22	10.43	10.16
	Interseeded	10.30	10.73	10.62	10.32	10.27	11.03
	Tame	11.16	11.20	11.55	11.78	10.24	11.15
1979	Native	9.50	9.80	10.26	10.86	10.87	
	Interseeded	11.66	11.54	11.58	11.86	11.38	
	Tame	10.06	11.05	11.49	11.59	11.40	
	Year						
	1978	10.43	10.62	10.69	10.78	10.32	
	1979	10.41	10.80	11.11	11.44	11.22	

Table 27. Estimated dry matter intake kg/day, for three grain levels at five pasture periods in 1978 and 1979. Based on Rohweder (1981) Method 4.

	Grain Level		
Pasture Period	0.0	0.5	1.0
1	9.07	10.32	11.87
2	9.13	10.75	12.25
3	9.10	11.00	12.60
4	9.10	11.29	12.92
5	8.60	10.83	12.87
Year			
1978	8.96	10.55	12.19
1979	9.04	11.12	12.82
Mean	9.00	10.84	12.50

V. Performance Of Grazing Steers On Pasture

Animal Performance on Pasture

Three pasture systems were evaluated over a three year period by yearling steers being supplemented on pasture at three grain levels. Average daily gain (ADG) on the three pasture systems were not different and the steers gained an average of 0.68 kg/day over the three year period. This appears to be consistent with other gains on pasture (McCone 1951, Blaser et al. 1956). Year, year X grain level, year X pasture system X grain level, pasture period X pasture system, pasture period X grain level and pasture period X pasture system X grain level were all different for ADG's. Analysis of variance for animal performance data are presented in Appendix Tables 27-29. Quasi F Tests and appropriate degrees of freedom are presented in Appendix Tables 30 and 31.

The lowest ADG's occurred in 1977 and it then increased each year of the grazing study (Table 28). A severe drought in 1976 probably retarded plant growth in 1977; plants tend to replenish root reserves after a drought before accumulating much top growth. Grain levels influenced ADG differently over years; grain supplementation increased ADG; however, only moderate increases in animal performance were found in 1977 and 1978 with grain supplementation. Animal gains were higher at the zero percent grain level in 1979 than in all other grain levels in the previous years. The reason for the increased animal production in 1979 is not clear, but the animals performed better at all grain levels. ADG's over the three year period were similar for the 0.5 and 1.0 percent grain level and they showed a 22 percent increase over the control.

ADG's varied with year X pasture system X grain levels (Table 29). Native range at 1.0 percent grain provided about the same ADG as the corresponding interseeded and tame pastures in 1977 and 1979 but had lower gains in 1978. ADG's on the interseeded range increased yearly with grain supplmentation always increasing animal performance but on a smaller scale than the other two systems. At the 0.5 and 1.0 percent grain levels, tame pastures were similar in ADG in 1977 and 1978.

Animal performance was followed through the growing season by pasture periods (Table 30). ADG of interseeded pasture, when compared to native and tame, was the highest and lowest of the three pasture systems at early (period 1) and late (period 5) grazing seasons, respectively. Very poor animal performance was found on the native and interseeded ranges in period 5. The decline in animal performance throughout the season and especially in late fall is probably due to poor forage quality. Quality estimates averaged about 40, 44, 69, 6.5, 6 and 7 percent for IVDMD, ADF, NDF, CP, lignin and silica, respectively. Russian wildrye in the tame grasses was grazed in the fifth period and even with the poor quality just described, cattle were able to gain weight at a very respectable level. Collectively, these factors indicate that animals reduce their forage consumption and rate of passage with the poor forage quality as found in period 5. This phenomenon has been described by Ellis (1978). Feeding of grain showed modest increases in ADG in the first four periods; the greatest effect of grain supplementation on ADG was at the 1.0 percent level in period 5.

Grazing steer performance varied by pasture system X pasture period X grain level (Table 31). Tame grasses and interseeded range provided about the same ADG's over the first four grazing periods at all grain levels. Period 5 gains were always lower on interseeded than on Russian wildrye. Native and interseeded steers consistently lost weight in period 5 at the 0 and 0.5 percent grain levels. At the 1.0 percent corn level animals were able to maintain their body weight. Energy supplementation at 0.5 percent body weight did not produce any weight gains in the native or interseeded ranges and the best supplementation and pasture at this period seems to be 1.0 percent body weight level and the tame pasture series.

Table 28. Average daily gain, kg, of steers with three levels of supplemental grain, 1977-1979 grazing seasons.

	Grazing Season			
Grain Level	1977	1978	1979	Mean
0.0	0.48	0.60	0.72	0.59
0.5	0.59	0.64	0.87	0.70
1.0	0.64	0.64	0.95	0.74
Mean	0.57	0.62	0.84	

Table 29. Average daily gain, Kg, of steers on three pasture systems and three grain levels, 1977-1979 grazing seasons.

	Pasture System		
Grain Level	Native	Interseeded	Tame
	1977		
0.0	0.48	0.48	0.46
0.5	0.58	0.59	0.63
1.0	0.65	0.62	0.66
	1978		
0.0	0.56	0.66	0.55
0.5	0.60	0.70	0.62
1.0	0.56	0.70	0.65

		1979	
0.0	0.66	0.77	0.74
0.5	0.88	0.89	0.84
1.0	1.02	0.90	0.94

Table 30. Average daily gain, kg, of steers on three pastures systems season-long and three grain levels season-long for 1977-1979.

Pasture System	Pasture Periods 1	2	3	4	5
Native	0.90	0.90	0.84	0.59	0.04
Interseeded	1.00	1.00	0.84	0.61	-0.01
Tame	0.95	0.95	0.78	0.65	0.37
Percent Grain Level					
0.0	0.88	0.89	0.68	0.54	0.03
0.5	0.96	0.94	0.92	0.64	0.07
1.0	1.01	1.02	0.86	0.66	0.29

Table 31. Average daily gain, kg, of steers of three pasture systems and three grain levels through the grazing season, 1977-1979.

Percent Grain Levels and Pasture Periods		Pasture System: Native	Interseeded	Tame
0.0 Grain				
Pasture Period	1	0.78	0.97	0.90
" "	2	0.72	0.98	0.96
" "	3	0.74	0.74	0.55
" "	4	0.55	0.61	0.54
" "	5	-0.01	-0.12	0.21
0.5 Grain				
Pasture Period	1	0.93	0.98	0.96
" "	2	0.97	0.98	0.86
" "	3	0.89	0.89	0.98
" "	4	0.59	0.65	0.69
" "	5	-0.14	-0.02	0.38
1.0 Grain				
Pasture Period	1	0.98	1.05	0.98
" "	2	1.02	1.03	1.03
" "	3	0.90	0.88	0.81
" "	4	0.63	0.65	0.71
" "	5	0.25	0.10	0.51

Animal Gains Per Ha and Carrying Capacity

succeeding

Animal gains per ha increased with each preceeding year of the grazing study (Table 32). Gains were about 60 percent lower for native than for interseeded and tame grasses. Steer gains per ha increased with increasing levels of grain supplementation and years had an influence on both pasture system and percent grain level gains.

Carrying capacity, AUM/ha, is an important method of expressing pasture and grain level affects on grazing animals. Tame and interseeded pasture carrying capacities were increased by 54 percent over the native range (Table 33). Grain supplementation on pasture at the 0.5 and 1.0 levels increased AUM/ha by 9 and 21 percent, respectively. Pasture system X grain level interaction showed that grain on interseeded range equaled the tame pasture series in carrying capacity and that interseeding at zero percent grain had a higher carrying capacity than the native range supplemented at 1.0 percent level of body weight.

AUM/ha were largest in 1978 followed by the 1977 and 1979 grazing seasons (Table 34). Year X pasture system and year X grain level interactions were found to differ in carrying capacity. Carrying capacity increased with pasture systems in 1977 and 1978 as follows, from lowest to highest: native, interseeded and tame grasses. In 1979 interseeded range was highest, followed by tame and native range.

Table 32. Total animal gains per ha, kg, of three pasture systems by years and three grain levels by years, 1977-1979 grazing season.

	Grazing Seasons			
Pasture System	1977	1978	1979	Mean
Native	21	23	29	24
Interseeded	29	39	48	39
Tame	35	39	39	38
Grain Level				
0.0	22	26	30	25
0.5	30	35	38	34
1.0	34	39	47	40
Mean	28	34	39	

Table 33. Carrying capacity, AUM/ha for three pasture systems and three grain levels, 1977-1979.

	Pasture System			
Grain Level	Native	Interseeded	Tame	Mean
0.0	0.30	0.45	0.50	0.42
0.5	0.36	0.50	0.52	0.46
1.0	0.37	0.58	0.59	0.51
Mean	0.34	0.42	0.53	

Table 34. Carrying capacity, AUM/ha of three pasture systems, grain levels for the 1977-1979 grazing seasons.

	Grazing Seasons		
Pasture System	1977	1978	1979
Native	0.34	0.37	0.32
Interseeded	0.49	0.54	0.53
Tame	0.57	0.60	0.44
Grain Level			
0.0	0.44	0.42	0.39
0.5	0.46	0.51	0.41
1.0	0.49	0.58	0.47
Mean	0.47	0.50	0.42

Production of Tame Series Components:

Production of the pasture components of the tame pasture series are shown on Tables 35-38. Significant yearly differences occurred in animal production; 1979 was the best year for animal production at all grain levels. ADG were high at all grain levels early and declined as the season progressed. ADG of the brome-alfalfa component, period 2, at 0.5 percent grain level was lower than or equal to zero grain level (Table 35). Grain supplementation started to be important in period 3 in the sudangrass pasture, especially in 1977 and 1979 (Tables 36 and 38). Grain supplementation at 0.5 percent increased ADG of sudangrass steers by 232 and 69 percent for the 1977 and 1979 grazing seasons, respectively. This large ADG increase in period 3 may be due to the fact that sudangrass, a C_4 species, typically has less digestible mesophyll cells than C_3 grasses. ADG of brome-alfalfa regrowth, period 4, were also greatly improved by grain supplementation. Brome-alfalfa regrowth has poor forage quality (Table 38), and is composed primarily of bromegrass with the alfalfa having been grazed out in period 2. In period 5, grain level also greatly increased average daily gain on the Russian wildrye pastures. The Russian wildrye component was completely matured, yet 400 kg animals continued to gain weight at the zero percent grain level.

Compared to the zero percent grain, the 0.5 percent grain level did not increase the carrying capacity, but the 1.0 percent grain level increased carrying capacity by 17 percent. Production increases at the 0.5 percent grain level came from increases in ADG at the 1.0 percent grain level and they came from increases in ADG and carrying capacity. Gains per ha over the three year period were increased by 34 and 54 percent at the 0.5 and 1.0 percent grain levels, respectively.

Table 35. Production of the different pasture components of a tame pasture series under three grain levels during the 1977, 1978 and 1979 grazing seasons.

Pasture Component and Pasture Period	Grain Level 0.0	0.5	1.0	Average
	Average Daily Gain, kg			
Crested wheatgrass, PP1	0.90	0.96	0.99	0.95
Brome-alfalfa, PP2	0.96	0.86	1.01	0.94
Sudangrass, PP3	0.55	0.99	0.81	0.79
Brome-alfalfa, PP4	0.54	0.69	0.71	0.65
Russian wildrye, PP5	0.21	0.38	0.51	0.37
	Animal unit day/ha			
Crested wheatgrass, PP1	91	86	106	94
Brome-alfalfa, PP2	59	57	69	64
Sudangrass, PP3	113	113	123	118
Brome-alfalfa, PP4	35	37	39	37
Russian wildrye, PP5	86	86	111	94
	Gain/ha			
Crested wheatgrass, PP1	115	120	148	128
Brome-alfalfa, PP2	79	78	98	85
Sudangrass, PP3	87	166	143	132
Brome-alfalfa, PP4	16	20	27	21
Russian wildrye, PP5	21	42	75	46

PP denotes pasture period

Table 36. Production of the different pasture components of a tame pasture series under three grain levels during the 1977 grazing season.

Pasture Component and Pasture Period	Grain Level 0.0	0.5	1.0	Average
		Average Daily Gain, kg		
Crested wheatgrass, PP1	0.80	0.81	0.87	0.83
Brome-alfalfa, PP2	0.87	0.69	0.86	0.81
Sudangrass, PP3	0.30	0.99	0.74	0.68
Brome-alfalfa, PP4	0.37	0.48	0.47	0.44
Russian wildrye, PP5	0.02	0.21	0.26	0.17
		Animal unit day/ha		
Crested wheatgrass, PP1	72	67	81	74
Brome-alfalfa, PP2	79	79	86	81
Sudangrass, PP3	146	143	151	146
Brome-alfalfa, PP4	25	25	25	25
Russian wildrye, PP5	113	104	113	111
		Gains/ha		
Crested wheatgrass, PP1	95	88	115	100
Brome-alfalfa, PP2	110	87	119	105
Sudangrass, PP3	67	226	177	157
Brome-alfalfa, PP4	14	18	18	17
Russian wildrye, PP5	3	36	49	29

PP denotes pasture period

Table 37. Production of the different pasture components of a tame pasture series under three grain levels during the 1978 grazing season.

Pasture Component and Pasture Period	Grain Level 0.0	0.5	1.0	Average
	Average Daily Gain, kg			
Crested wheatgrass, PP1	0.91	1.06	0.86	0.94
Brome-alfalfa, PP2	0.97	0.88	1.00	0.95
Sudangrass, PP3	0.72	0.80	0.68	0.73
Brome-alfalfa, PP4	0.40	0.45	0.60	0.48
Russian wildrye, PP5	0.21	0.31	0.29	0.27
	Animal unit day/ha			
Crested wheatgrass, PP1	104	106	121	111
Brome-alfalfa, PP2	47	57	57	54
Sudangrass, PP3	101	109	126	111
Brome-alfalfa, PP4	54	59	67	59
Russian wildrye, PP5	91	92	126	104
	Gains/ha			
Crested wheatgrass, PP1	131	160	147	146
Brome-alfalfa, PP2	64	73	87	75
Sudangrass, PP3	105	125	122	118
Brome-alfalfa, PP4	31	39	58	42
Russian wildrye, PP5	28	42	51	40

PP denotes pasture period

Table 38. Production of the different pasture components of a tame pasture series under three grain levels during the 1979 grazing season.

Pasture Component and Pasture Period	Grain Level 0.0	0.5	1.0	Average
		Average Daily Gain, kg		
Crested wheatgrass, PP1	0.89	0.92	1.11	0.98
Brome-alfalfa, PP2	0.94	0.93	1.05	0.98
Sudangrass, PP3	0.61	1.03	0.94	0.86
Brome-alfalfa, PP4	0.83	1.07	1.01	0.97
Russian wildrye, PP5	0.40	0.60	0.94	0.65
		Animal unit day/ha		
Crested wheatgrass, PP1	96	86	111	99
Brome-alfalfa, PP2	49	57	62	57
Sudangrass, PP3	99	91	91	94
Brome-alfalfa, PP4	22	25	27	25
Russian wildrye, PP5	52	57	89	67
		Gains/ha		
Crested wheatgrass, PP1	120	110	182	138
Brome-alfalfa, PP2	66	75	91	77
Sudangrass, PP3	91	146	133	123
Brome-alfalfa, PP4	2	3	3	3
Russian wildrye, PP5	31	48	123	67

PP denotes pasture period

Grain Efficiency

The efficiency of grain for increasing animal performance is presented in Table 39. Data shows that feeding grain to provide energy for the grazing animal throughout the grazing season is not very efficient. Embry (1973, 1976) and Embry and Bush (1979) found much greater efficiencies in converting grain energy on pasture to animal gains than in this study. From this study feeding supplemental energy on pasture should be considered at selected grazing periods, such as periods 4 and 5, when forage quality has declined. The advantage of grain when fed throughout the grazing season was that it allowed for a greater stocking rate to be achieved on pasture without a reduction in animal gains.

Table 39. Grain efficiency for improving total animal gains, kg, for three pasture systems and three grain levels, 1977-1979.

	Grain Level		
	0.0	0.5	1.0
	Native range (156 day grazing season)		
ADG	0.57	0.64	0.58
Gain/Animal	88	99	91
Corn fed/day	--	1.68	3.35
Corn fed/season	--	263	522
Corn/45.4 kg gain	--	120	261
Gain over zero % corn per kg corn fed	--	0.02	0.004
	--		
	Interseeded range (156 day grazing season)		
ADG	0.69	0.73	0.69
Gain/Animal	108	114	108
Corn fed/day	--	1.69	3.38
Corn fed/season	--	264	528
Corn/45.4 kg gain	--	106	221
Gain over zero % corn per kg corn fed	--	0.01	0.002
	--		
	Tame grasses (178 day grazing season)		
ADG	0.74	0.74	0.75
Gain/Animal	133	132	134
Corn fed/day	--	1.72	3.51
Corn fed/season	--	306	626
Corn/45.4 kg gain	--	106	238
Gain over zero % corn per kg corn fed	--	0.0	0.003
	--		

Ha Required Per Animal Unit

The approximate number of ha required to carry an animal unit (AU), through the grazing season under three pasture systems and grain levels is show in Table 40. At zero percent grain supplementation, native range required about 32 percent more ha per AU than the interseeded and tame pasture series. Interseeded range required about 0.69 ha less to carry an AU than native range. The 1.0 percent grain level decreased the required ha/AU by 19, 13 and 14 percent of native, interseeded and tame pastures over the zero percent grain level, respectively.

Table 40. Approximate number of ha required to carry an animal unit for the entire grazing season by pasture system and grain level, 1977-1979.

	Grain Level		
Pasture System	0.0	0.5	1.0
Native	2.84	2.39	2.31
Interseeded	1.90	1.66	1.66
Tame	1.94	1.86	1.66

VI. Prediction of Mean Average Animal Daily Gain On Pasture

Multiple regression analyses were used to predict mean average daily gain (MADG) for grazing steers on a particular pasture. Estimates of Van Soest's DMI and chemical analysis were first used in a stepwise multiple regression with steer ADG as the dependent variable. Estimates of ADG by this regression analysis showed that DMI was entered in step one with an R^2 = 25.7 and SD of 0.412. When IVDMD was entered in the second step, R^2 increased to 72.6 and SD decreased to 0.256. The regression equation that was developed is:

$$ADG = 2.09988 + 0.04295 \times DMI + 0.04036 \times IVDMD$$

The decision was made that the product of DMI and IVDMD was superior to using either variable alone and the term "estimated digestible forage intake" (EDFI) was coined, where IVDMD was divided by 100. EDFI and other standard chemical components were used as independent variables and multiple regression analysis were used to predict ADG of an individual grazing steer on pasture. A regression equation with an R^2 = 90.6 and SD = 0.146 was found and follows as:

$$\text{ADG of an individual grazing steer} = 1.57157 + 0.29301 \times EDFI - 0.01467 \times EDFI^2 + 0.000284 \times EDFI^3 + 0.064726 \times NDF - 0.00084 \times NDF^2$$

Realizing that collinarity existed between ADG, the dependent variable, and DMI and EDFI as an independent variables, asubstitute equation that estimated ADG of an individual grazing steer was developed to replace the known ADG as shown in Lofgreen and Garrett's (1968) formula for NE_{gain} of the animal. This substitute equation is shown and discussed in the Material and Methods.

Best prediction MADG equations for a group of growing steers on pasture with their respective R^2 and SD are presented in Table 41. Ten equations are presented with R^2 ranging from 35.7 to 52.6 and SD of 0.218 to 0.325. All equations are summed for the 1978 and 1979 grazing seasons and all require an estimate of animal body weight for the grazing animal (Materials and Methods).

Pasture systems were not found as a significant independent variables in Equations 2, 3 and 4 although pasture systems did occur in the remaining seven equations (Table 41). Equations 1, 2, 3 and 4 are recommended to predict MADG of grazing steers on pasture. Equation 1 requires lignin and silica in addition to IVDMD, NDF, an estimate of body weight and pasture period when the animal will graze. Lignin and silica determinations are fairly laborious and expensive, thus Equation 2 is more practical but with a slightly lower R^2. Equation 2 requires a routine and relatively inexpensive ADF determination along with IVDMD and NDF as forage quality measures and animal body weight and pasture period. It is proposed that for research work, where IVDMD is determined on large numbers of forage plant samples, Equation 2 be given serious consideration. Since we substitute IVDMD for TDN in the Van Soest formulas, TDN, another standard laboratory procedure, should be determined; TDN along with ADF, NDF, weight of the animal and pasture period, are required for Equations 3 and 4, making them practical for farmer-producer use. Many laboratories do not have the facilities for IVDMD determinations. Coefficients of determination (R^2) are several percentage points lower with Equations 3 and 4 but about the same results will be found and at considerable savings in laboratory analysis. Equations 5-10 are not recommended for use by either researchers or producers. An example of predicted MADG using Equation 2 at three grain levels is shown in Appendix Table 32.

Forage quality data is in abundance in the literature, but in only a few cases has forage quality been related to animal performance. IVDMD and animal performance have been correlated in two studies, Duble et al. (1971) and Hedrick et al. (1982). R values of 0.85 and 0.73 were found using IVDMD in these respective studies. However, neither study estimated dry matter intake and from our initial results we found DMI to be superior to IVDMD, with IVDMD times DMI explaining about 72 percent of the animal weight variations on pasture. It seems reasonable that food must be taken into the body before a nutritive value can be obtained. Thus, we think that EDFI, which is the product of estimated DMI and IVDMD; and our prediction equations 1, 2, 3 and 4, are superior to those of Duble et al. (1971) and Hedrick et al. (1982).

Table 41. Regression Equations for predicting mean steer ADG in pastures from estimates of forage dry matter intake, laboratory analysis, animal weights and grazing periods.

Equation 1: Uses Van Soest 1971 DMI and IVDMD:

Mean ADG in kg = 3.48 - 0.0131 X EDFI1 - 0.109 X NDF + 0.00119 X NDF^2 - 1.94 X 1/Lignin + 1.53 X 1/Silica - 0.196 X Interseeded Pasture + 0.188 X Tame Pasture + 0.0501 X GE. R^2 = 52.6 SD = 0.281

Equation 2: Uses Van Soest 1973b DMI and IVDMD:

Mean ADG in kg = 0.344 - 0.00338 X EDFI2 - .000057 X $EDFI2^2$ + 1.93 X 10^{-7} X $EDFI2^3$ + 0.0541 X RFV - 0.000208 X RFV^2 - 0.0936 X NDF + 0.000979 X NDF^2 + 0.044 X GNE. R^2 = 51.0 SD = 0.286

Equation 3: Uses Van Soest 1971 DMI and DDM:

Mean ADG in kg = 1.87 - 0.00667 X EDFI6 - 0.201 X NDF + 0.00204 X NDF^2 + 0.0636 X RFV - 0.000248 X RFV^2 + 0.047 X GNE. R^2 = 48.8 SD = 0.291

Equation 4: Uses Van Soest 1973b DMI and ADF:

Mean ADG in kg = -0.925 - 0.00208 X EDFI7 - 0.000024 X $EDFI7^2$ + 5.56 X 10^{-8} X $EDFI7^3$ + 0.0671 X RFV - 0.000258 X RFV^2 - 0.105 X NDF + 0.0011 X NDF^2 + 0.0425 X GNE. R^2 = 49.2 SD = 0.291

Equation 5: Uses Colburn and Evans 3A DMI and IVDMD:

Mean ADG in kg = -4.48 + 0.0576 X $EDFI3^2$ - 0.0071 X $EDFI3^3$ + 0.0194 X NDF + 0.014 X CP + 1.16 X 1/Silica + 0.0546 X RFV - 0.000209 X RFV^2 - 0.186 X Interseeded Pasture - 0.113 X Tame Pasture. R^2 = 37.8 SD = 0.322

Equation 6: Uses Colburn and Evans 3B DMI and IVDMD:

Mean ADG in kg = -2.52 + 0.0528 X RFV - 0.000218 X RFV^2 + 0.991 X 1/Silica - 0.14 X Interseeded Pasture + 0.0404 X GNE. R^2 = 35.7 SD = 0.325

Equations 7: Uses Rohweder DMI and IVDMD:

Mean ADG in kg = -2.59 - 0.000528 X $EDFI5^3$ + 0.0178 X CP + 1.23 X 1/Silica + 0.051 X RFV - 0.000214 X RFV^2 - 0.164 X Interseeded Pasture + 0.069 X GNE. R^2 = 37.1 SD = 0.323

Table 41. Continued

Equations 8: Uses Colburn and Evans 3A DMI and DDM:

Mean ADG in kg = -4.01 + 0.058 X RFV - 0.000229 X RFV^2 + 0.012 X CP + 1.22 X 1/Silica + 0.015 X NDF - 0.164 X Interseeded Pasture - 0.0719 X Tame Pasture + 0.0399 X GNE. R^2 = 37.0 SD = 0.324

Equation 9: Uses Colburn and Evans 3B DMI and DDM:

Mean ADG in kg = -2.52 + 0.0528 X RFV - 0.000218 X RFV^2 + 0.991 X 1/Silica - 0.140 X Interseeded Pasture + 0.0404 X GNE. R^2 = 35.7 SD = 0.325

Equation 10: Uses Rohweder DMI and DDM:

Mean ADG in kg = -2.52128 + 0.0528 X RFV - 0.000218 X RFV^2 + 0.991 X 1/Silica - 0.140 X Interseeded Pasture + 0.0404 X GNE. R^2 = 35.7 SD = 0.325

SUMMARY AND CONCLUSIONS

Three pasture systems: native, native-interseeded range and a tame grass pasture series, with and without supplemental energy, were evaluated by grazing yearling Hereford steers. Qualitative season-long changes in pasture herbage were evaluated with IVDMD and other standard laboratory procedures. In addition, estimates of dry matter intake, chemical constituents of herbage and animal weight within a pasture period were used to predict animal performance on pasture.

Pasture systems did not differ in average daily gain over a three year period; however, gains per ha and carrying capacity of interseeded and tame pastures were increased by 60 and 54 percent, respectively, over the native range. The study showed that under a pasture situation beef production of a native range can be increased 60 plus percent by the intoduction of a legume component as the sole management modification. ADG's increased each year of the grazing study and generally declined with advance of the grazing season (pasture period). Grain supplementation at all levels did not greatly influence animal performance during the first four pasture periods, with the 1.0 percent level providing enough energy in period 5 for cattle to maintain or gain weight. Cattle at zero and 0.5 percent level consistently lost weight on native and interseeded ranges in period 5. Excellent animal responses at the 0.5 percent level for sudangrass were found, with only slight differences for the other tame pasture components and grain levels. Very low efficiency of supplemented grain energy to animal weight gain was found in this study. About 32 percent more land acreage is required to carry an animal unit on native range than on interseeded or tame grass pastures.

Quality of forage declines with the grazing season. Tame grass pastures were higher in quality than other pasture systems, except in late fall grazing when they were equal. Interseeded ranges were superior to native range in quality when alfalfa was available for grazing. No differences were found between native grass associated with alfalfa in the interseeded range and the native grass range. Alfalfa is a major influence for increasing forage quality of rangelands. Generally, IVDMD and CP decreased, with ADF, NDF, lignin and silica increasing with plant maturity.

Five different methods were used to estimate dry matter intake of grazing steers. Two Van Soest methods were found to give higher DMI estimates than others because these allowed for partitioning of forage and animal maintenance and gain, with forage quality taken into consideration. A new term "estimated digestible forage intake" (EDFI) was coined to describe the product of estimated DMI and forage digestibility. EDFI, IVDMD, ADF, NDF, CP, lignin, silica, estimates of animal body weight, pasture period and pasture systems were utilized in different multiple regression analyses to predict mean ADG of a group of grazing steers.

Three equations are recommended to predict MADG of steers on pasture. These equations are:

Equation 2: Uses Van Soest 1973b DMI and IVDMD: mean ADG in Kg = $-0.344 - 0.00338 \times EDFI2 - 0.000057 \times EDFI2^2 + 1.93 \times 10^{-7} \times EDFI2^3 + 0.054 \times RFV - 0.000208 \times RFV^2 - 0.0936 \times NDF + 0.000979 \times NDF^2 + 0.044 \times GNE$. $R^2 = 51.0$ SD = 0.286.

Equation 3: Uses Van Soest 1971 DMI and DDM:
Mean ADG in Kg = 1.87 - 0.00667 X EDFI6 - 0.201 X NDF + 0.00204 X NDF^2 + 0.0636 X RFV - 0.00248 X RFV^2 + 0.0471 X GNE. R^2 = 48.8 SD = 0.291.

Equation 4: Uses Van Soest 1973b DMI and DDM:
Mean ADG in Kg = -0.925 - 0.00208 X EDFI7 - 0.000024 X $EDFI7^2$ + 5.56 X 10^{-8} X $EDFI7^3$ + 0.0671 X RFV - 0.000258 X RFV^2 - 0.105 X NDF + 0.0011 X NDF^2 + 0.0425 X GNE. R^2 = 41.2 SD = 0.291.

Equation 1 is recommended for research use while equations 2 and 3 are recommended for farmer-rancher use because these are more practical and require fewer chemical analyses. The IVDMD procedure needed in Equation 1 is very time consuming and requires the constant availability of a fistulated animal on a complete roughage ration.

It was hypothesized that interseeding native range with a pasture-type alfalfa, such as 'Travois', could help make these lands more productive. In the interseeded pasture, alfalfa was the single most abundant and evenly distributed species. Interseeding appears to enhance the sod-forming grasses and may slightly suppress the bunchgrass species in the native ranges.

Forage dry matter production is highly dependent upon precipitation in the Great Plains. Available forage for grazing was highest in 1978 and alfalfa contributed about 35 percent of the available forage during the spring and summer months. The drier spring in 1979 suppressed native grass growth and increased the alfalfa contribution to about 65 percent of the forage in interseeded ranges. Large differences were found in sudangrass relative yields, depending upon the season. Available forage remaining averaged greater than 1100 kg/ha on native and interseeded ranges and less than 360 kg/ha on Russian wildrye in early November.

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34

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APPENDIX

APPENDIX TABLE 1

Computer Program Designed To Estimate Dry Matter Intake Of Grazing Steers On Pasture

```
 10  Title Program designed to calculate dry matter intake;
 20  Title By five different methods;
 30  Data DRY MAT IN;
 40  INPUT YEAR PAST REP PASTP ANIM PCTGRN DAYS
 50  ADGP IW FW IVDMD NDF;
 60  ADGK = ADGP X 0.454; MPWP = (IW + FW)/2; MPWK = MPWP X 0.454;
 70  NEGF = 0.0078 X IVDMD X (2.86 - (35.5/(100-NDF))) - 0.41;
 80  NEMF = 0.99 X NEGF + 0.69;
 90  NEGA = (0.05272 X ADGK + 0.00684 X ADGK XX 2) X EXP (0.75 X LOG (MPWK));
100  NEMA = 0.077 X EXP (0.75 X LOG (MPWK));
110  NEGF3 = 0.029 X IVDMD - 1.01;
120  NEMF3 = 0.029 X IVDMD - 0.29;
130  NEGFG = NEGA/NEGF;
140  NEGFG3 = NEGA/NEGF3;
150  GNE = IW X PCTGRN X 0.454;
160  DMI3A = 0.297 X EXP (0.54 X LOG (MPWK));
170  DMI3B = 0.091 X EXP (0.75 X LOG (MPWK));
180  DMI4 = (0.0847 - 0.00369 X NDF + 0.03237 X SQRT (NDF)) X EXP
       (0.75 X LOG (MPWK));
190            IF ADG < 0.00 THEN DO;
200            NEL = ((IW-FW) X 2.724)/DAYS;
210            FNFM = (NEMA-NEL)/NEGF + 0.72);
220            FNFM3 = (NEMA-NEL)/NEMF3;
230            DMI1 = FNFM + GNE;
240            DMI2 = FNFM3 + GNE;
250  END;
260  ELSE DO;
270            FNFM = NEMA/NEMF;
280            FNFM3 = NEMA/NEMF3;
290            DMI1 = FNFM + NEGFG + GNE;
300            DMI2 = FMFM3 + NEGFG3 + GNE;
310  END;
320  CARDS;
```

<u>Documentation</u>

DMI1 = Van Soest 1971, Method 1
DMI2 = Van Soest 1973b, Method 2
DMI3A = Colburn and Evans 1968, Method 3A
DMI3B = Colburn and Evans 1968, Method 3B
DMI4 = Rohweder 1981, Method 4
NEMF = Net energy maintenance from 1971 Van Soest forage
NEGF = Net energy gain from 1971 Van Soest forage
NEMF3 = Net energy maintenance from 1973b Van Soest forage
NEGF3 = Net energy gain from 1973b Van Soest forage
NEMA = Net energy maintenance of the animal
NEGA = Net energy gain of the animal
GNE = Grain energy

APPENDIX TABLE 2

Example Of Calculating DMI For Van Soest 1971, Method 1

Data Imput: IVDMD = 60.00
NDF = 48.00

Animal Wt = 227 kg
ADG = 0.68 kg/day
0 Percent grain level

A. Forage Maintenance and Gain:

1. $NE_{Lactation} = 0.01\ TDN\ (2.86 - (35.5/100 - NDF\%))$
2. $NE_{gain} = 0.70\ NE_{lact.} - 0.41$ in Mcal/kg
3. $NE_{maint.} = 0.99\ NE_{gain} + 0.69$ in Mcal/kg

Thus:

1. $NE_{Lact.} = 0.01 \times 60.00\ (2.86 - (35.5/100 - 48))$
   $NE_{Lact.} = 1.31$
2. $NE_{gain} = 0.70 \times 1.31 - 0.41 = 0.51$ Mcal/kg
3. $NE_{maint.} = 0.99 \times 0.51 + 0.69 = 1.19$ Mcal/kg

B. Animal Maintenance and Gain:

1. $NE_{maint.} = 0.077\ W^{0.75}$ in Mcal/animal/day
2. $NE_{gain} = (52.72\ g + 6.84g^2\ (W^{0.75})$ in Kcal/animal/day

Thus:

1. $NE_{maint.}$ for animal $= 0.077 \times 227^{0.75} = 4.50$ Mcal/animal/day
2. NE_{gain} for animal $= (52.72 \times 0.68 + 6.84 \times 0.68^2)\ (227^{0.75}) = (39.01)\ (58.48) = 2281$ Kcal/animal/day or 2.281 Mcal/aniaml/day

C. Kg dry matter (DM) needed for maintenance and gain:

1. $\frac{NE_{maint.} \text{ of the animal}}{NE_{maint.} \text{ of the forage}}$ = kg DM for maintenance

2. $\frac{NE_{gain} \text{ of the animal}}{NE_{gain} \text{ of the forage}}$ = kg DM for maintenance

Thus:

1. $\frac{4.50 \text{ Mcal/animal/day}}{1.19 \text{ Mcal/day}}$ = 3.78 kg DM for maintenance

2. $\frac{2.281 \text{ Mcal/animal/day}}{0.51 \text{ Mcal/kg}}$ = 4.47 kg DM for gain

APPENDIX TABLE 2 CONTINUED

D. Total Intake:

Kg dry matter maint. + kg dry matter gain = total kg dry matter intake.

Thus:

3.78 + 4.47 = 8.25 kg DM intake/animal/day

APPENDIX TABLE 3

Precipitation and mean temperature for 1977 at Faulkton, South Dakota.

Month	Temperature (C)				Precipitation (cm)	
	Average Maximum	Average Minimum	Monthly Average	Departure From Normal	Total	Departure From Normal
January	- 9.3	-22.0	-15.6	-4.9	0.51	- 0.15
February	3.7	- 9.0	- 2.7	5.2	3.66	2.36
March	7.3	- 4.2	1.6	3.4	12.06	10.13
April	20.4	3.6	12.0	4.5	4.06	- 1.17
May	26.1	10.6	18.4	4.7	5.33	- 1.98
June	28.5	12.9	20.7	1.9	9.14	- 1.57
July	32.5	15.2	23.9	1.5	4.50	- 1.60
August	28.7	11.4	20.1	-1.8	3.58	- 1.90
September	24.2	9.4	16.8	1.0	8.74	4.85
October	16.9	2.0	9.5	-0.2	3.18	0.08
November	3.5	- 7.4	- 1.9	-2.2	6.07	4.60
December	- 5.7	-14.6	-10.1	-2.9	1.24	0.46

APPENDIX TABLE 4

Precipitation and mean temperature for 1978 at Faulkton, South Dakota

Month	Temperature (C)				Precipitation (cm)	
	Average Maximum	Average Minimum	Monthly Average	Departure From Normal	Total	Departure From Normal
January	-11.8	-23.5	-17.6	-6.9	0.48	-0.56
February	- 8.7	-17.8	-13.2	-5.4	0.79	-0.51
March	3.6	- 7.4	- 1.9	0.0	0.61	-1.32
April	12.5	1.5	7.0	-0.5	7.23	2.01
May	22.0	7.7	14.8	1.2	9.07	1.75
June	27.4	11.7	19.5	0.7	5.97	-4.78
July	29.5	14.9	22.3	-0.1	6.02	-0.08
August	31.0	14.4	22.7	0.8	10.29	4.80
September	28.6	11.1	19.9	4.0	1.14	-2.74
October	19.6	1.0	10.3	0.6	0.13	-2.97
November	3.6	- 9.0	- 2.7	-2.9	1.85	0.38
December	- 4.9	-14.7	- 9.8	-2.7	0.43	-0.36

APPENDIX TABLE 5

Precipitation and mean temperature for 1979 at Faulkton, South Dakota.

	Temperature (C)				Precipitation (cm)	
Month	Average Maximum	Average Minimum	Monthly Average	Departure From Normal	Total	Departure From Normal
January	-11.9	-23.9	-17.9	-7.2	1.42	0.38
February	- 9.5	-21.7	-15.6	-7.8	1.07	-0.22
March	3.7	- 7.3	- 1.8	0.1	3.76	1.83
April	12.6	- 0.4	6.2	-1.3	5.05	-0.18
May	19.9	4.1	12.0	-1.6	2.95	-4.37
June	27.3	11.5	19.4	0.6	6.58	-4.16
July	28.8	15.2	22.0	-0.4	8.13	2.03
August	27.9	13.6	20.7	-1.1	16.69	11.20
September	27.9	9.7	18.8	2.9	0.00	-3.89
October	17.8	0.4	9.1	-0.6	4.85	1.75
November	4.4	- 6.7	- 1.1	-1.3	0.28	-1.19
December	6.0	-10.2	- 2.0	5.1	0.05	-0.74

APPENDIX TABLE 6

Analysis of Variance for IVDMD, Short-Season

Source	Df	SS	F
Total	323	19792.196	--
Model	107	17204.350	--
Year (Y)	1	15.778	0.18
Treatment (T)	2,4	4258.976	8.59*
Y X T	2	349.271	2.63
Date	4,7	10353.998	27.178**
Y X D	5	327.425	7.95**
T X D	16,15	304.647	1.37
Y X T X D	10	231.699	2.72*
Rep (R)	2	122.054	0.70
Y X R	2	175.136	7.31**
T X R	4	323.740	1.22
Y X T X R	4	265.487	5.54**
D X R	10	110.129	1.33
Y X D X R	10	82.355	0.69
T X D X R	20	109.134	0.62
Y X T X D X R	20	174.519	0.73
Error	216	2587.847	--

APPENDIX TABLE 7

Analysis of Variance for IVDMD, Long-Season

Source	Df	SS	F
Total	287	21594.406	--
Model	95	19516.506	--
Year (Y)	1	15.494	0.13
Treatment (T)	1,2	3575.760	11.85
Y X T	1	211.494	2.54
Date	7,10	13397.926	32.88**
Y X D	7	343.774	11.52**
T X D	10,13	344.763	0.91
Y X T X D	7	324.061	4.25**
Rep (R)	2	88.102	0.37
Y X R	2	240.242	11.10**
T X R	2	194.581	1.17
Y X T X R	2	166.430	7.69**
D X R	14	129.062	2.16
Y X D X R	14	59.670	0.39
T X D X R	14	272.825	1.79
Y X T X D X R	14	152.321	1.01
Error	192	2077.900	--

APPENDIX TABLE 8

Analysis of Variance for ADF, Short-Season

Source	Df	SS	F
Total	323	6727.356	--
Model	107	5383.089	--
Year (Y)	1	879.782	120.67**
Treatment (T)	2,2	1009.016	2.21
Y X T	2	447.791	8.75**
Date	5,7	2358.217	59.37**
Y X D	5	34.762	1.16
T X D	20,14	85.498	0.78
Y X T X D	10	134.926	2.99*
Rep (R)	2	37.892	2.60
Y X R	2	14.582	1.17
T X R	4	61.572	0.60
Y X T X R	4	102.363	4.11**
D X R	10	10.918	0.18
Y X D X R	10	59.754	0.96
T X D X R	20	55.810	0.62
Y X T X D X R	20	90.206	0.72

APPENDIX TABLE 9

Analysis of Variance for ADF, Long-Season

Source	Df	SS	F
Total	287	7964.250	--
Model	95	7046.534	--
Year (Y)	1	532.467	128.98**
Treatment (T)	1,1	237.257	0.67
Y X T	1	398.560	12.51
Date	7,10	4882.002	47.85**
Y X D	7	83.607	12.21**
T X D	8,9	365.960	1.85
Y X T X D	7	185.974	5.52**
Rep (R)	2	15.076	1.83
Y X R	2	8.256	0.86
T X R	2	39.481	0.62
Y X T X R	2	63.705	6.66**
D X R	14	37.868	0.55
Y X D X R	14	69.072	1.03
T X D X R	14	59.942	0.89
Y X T X D X R	14	67.314	1.01

APPENDIX TABLE 10

Analysis of Variance for NDF, Short-Season

Source	Df	SS	F
Total	323	16841.559	--
Model	107	15310.933	--
Year (Y)	1	29.461	2.42
Treatment (T)	2,2	6988.600	7.26
Y X T	2	956.803	19.78**
Date	5,15	5868.275	73.03**
Y X D	5	20.730	0.34
T X D	11,16	578.845	2.62
Y X T X D	10	182.139	3.70*
Rep (R)	2	84.000	3.45
Y X R	2	24.369	1.72
T X R	4	24.932	0.26
Y X T X R	4	96.748	3.41**
D X R	10	120.909	1.00
Y X D X R	10	121.033	1.71
T X D X R	20	115.699	1.18
Y X T X D X R	20	98.388	0.69
Error	[illegible]	[illegible]	[illegible]

APPENDIX TABLE 11

Analysis of Variance for NDF, Long-Season

Source	Df	SS	F
Total	287	18988.029	--
Model	95	17773.249	--
Year (Y)	1	102.961	31.06*
Treatment (T)	1,1	4059.005	5.50
Y X T	1	736.001	17.71
Date	7,20	10072.247	67.30**
Y X D	7	67.728	15.08**
T X D	7,8	1925.406	5.84**
Y X T X D	7	307.326	9.69**
Rep (R)	2	48.703	7.34
Y X R	2	6.631	0.52
T X R	2	17.644	0.21
Y X T X R	2	83.128	6.57**
D X R	14	164.791	2.62
Y X D X R	14	62.865	0.71
T X D X R	14	55.360	0.87
Y X T X D X R	14	63.454	0.72
Error	192	1214.780	--

APPENDIX TABLE 12

Analysis of Variance for CP, Short-Season

Source	Df	SS	F
Total	323	2165.399	--
Model	107	1917.392	--
Year (Y)	1	251.927	128.36**
Treatment (T)	2,3	698.523	19.67*
Y X T	2	27.677	3.52
Date	5,6	663.593	11.26**
Y X D	5	54.361	13.74**
T X D	14,21	81.846	5.64**
Y X T X D	10	11.045	0.75
Rep (R)	2	32.799	8.36
Y X R	2	3.925	1.71
T X R	4	16.487	1.05
Y X T X R	4	15.737	3.43**
D X R	10	9.801	1.23
Y X D X R	10	7.915	0.69
T X D X R	20	12.153	0.61
Y X T X D X R	20	29.599	1.29

APPENDIX TABLE 13

Analysis of Variance for CP, Long-Season

Source	Df	SS	F
Total	287	2866.749	--
Model	95	2661.015	--
Year (Y)	1	200.000	116.57**
Treatment (T)	1,2	486.200	13.93
Y X T	1	25.920	4.65
Date	7,9	1570.504	30.17**
Y X D	7	45.065	7.10**
T X D	8,17	203.140	10.84**
Y X T X D	7	11.699	6.39**
Rep (R)	2	16.854	4.91
Y X R	2	3.431	1.60
T X R	2	18.750	1.68
Y X T X R	2	11.140	5.20**
D X R	14	14.394	1.13
Y X D X R	14	12.694	0.85
T X D X R	14	17.526	0.72
Y X T X D X R	14	24.287	1.62
Error	192	205.733	--

APPENDIX TABLE 14

Analysis of Variance of Lignin, Short-Season

Source	Df	SS	F
Total	71	82.031	--
Model	35	77.961	--
Year (Y)	1	0.161	1.42
Treatment (T)	2	36.881	5.32
Y X T	2	6.938	30.68**
Date (D)	5	27.148	10.12**
Y X D	5	2.683	4.75**
T X D	10	3.102	2.96
Y X T X D	10	1.045	0.93
Error	36	4.070	--

APPENDIX TABLE 15

Source	Df	SS	F
Total	63	89.505	--
Model	31	85.970	--
Year (Y)	1	1.856	16.80**
Treatment (T)	1	43.066	8.23
Y X T	1	5.233	47.37**
Date	7	26.001	6.30*
Y X D	7	4.130	5.34**
T X D	7	4.655	4.52
Y X T X D	7	1.028	1.33
Error	32	3.535	--

APPENDIX TABLE 16

Analysis of Variance for Silica, Short-Season

Source	Df	SS	F
Total	71	163.590	--
Model	35	163.115	--
Year (Y)	1	0.420	31.84**
Treatment (T)	2	93.617	11.07
Y X T	2	8.455	320.41**
Date	5	54.769	73.77**
Y X D	5	0.742	11.25**
T X D	10	2.731	1.15
Y X T X D	10	2.380	18.04**

APPENDIX TABLE 17

Analysis of Variance for Silica, Long-Season

Source	Df	SS	F
Total	63	230.687	--
Model	31	230.142	--
Year (Y)	1	0.008	0.45
Treatment (T)	1	107.381	12.03
Y X T	1	8.925	524.05**
Date	7	105.988	26.81**
Y X D	7	3.954	33.16**
T X D	7	2.679	2.22
Y X T X D	7	1.206	10.1**
Error	32	0.545	--

APPENDIX TABLE 18

Quasi F's for both Short and Long-Season Forage Quality Analyses

$$\text{Treatment} = \frac{\text{M.S. Trt} + \text{M.S. Y X Trt X R}}{\text{M.S. Y X Trt} + \text{M.S. Trt X R}}$$

$$\text{Date} = \frac{\text{M.S. Date} + \text{M.S. Y X Date X R}}{\text{M.S. Y X Date} + \text{M.S. Date X R}}$$

$$\text{Treatment X Date} = \frac{\text{M.S. Trt X Date} + \text{M.S. Y X Trt X Date X R}}{\text{M.S. Y X Trt X Date} + \text{M.S. Trt X Date X R}}$$

Documention:

Trt = Treatment
Y = Year
R = Rep

APPENDIX TABLE 19

Degrees of Freedom for both Short and Long-Season Forage Quality Analyses

$$\text{Treatment} = \frac{\dfrac{(\text{M.S. Trt} + \text{M.S. Y X Trt X R})^2}{\dfrac{(\text{M.S. Trt})^2}{\text{Trt df}} + \dfrac{(\text{M.S. Y X Trt X R})^2}{\text{Y X Trt X R df}}}}{\dfrac{(\text{M.S. Y X Trt} + \text{M.S. Trt X R})^2}{\dfrac{(\text{M.S. Y X Trt})^2}{\text{Y X Trt df}} + \dfrac{(\text{M.S. Trt X R})^2}{\text{Trt X R df}}}}$$

$$\text{Date} = \frac{\dfrac{(\text{M.S. Date} + \text{M.S. Y X Date X R})^2}{\dfrac{(\text{M.S. Date})^2}{\text{Date df}} + \dfrac{(\text{M.S. Y X Date X R})^2}{\text{Y X Date X R df}}}}{\dfrac{(\text{M.S. Y X Date} + \text{M.S. Date X R})^2}{\dfrac{(\text{M.S. Y X Date})^2}{\text{Y X Date df}} + \dfrac{(\text{M.S. Date X R})^2}{\text{Date X R df}}}}$$

$$\frac{\dfrac{(\text{M.S. Trt X Date} + \text{M.S. Y X Trt X Date XR})^2}{\dfrac{(\text{M.S. Trt X Date})^2}{\text{Trt X Date df}} + \dfrac{(\text{M.S. Y X Trt X Date X R})^2}{\text{Y X Trt X Date X R df}}}}{\dfrac{(\text{M.S. Y X Trt X Date} + \text{M.S. Trt X Date X R})^2}{\dfrac{(\text{M.S. Y X Trt X Date})^2}{\text{Y X Trt X Date df}} + \dfrac{(\text{M.S. Trt X Date X R})^2}{\text{Trt x Date X R df}}}}$$

Documentation:

Trt = Treatment
Y = Year
R = Rep
df = degrees of freedom

APPENDIX TABLE 20

Analysis of Van Soest 1971 Method 1 Estimated DMI

Source	Df	SS	F
Total	1619	157799.098	--
Model	269	116286.641	--
Year (Y)	1	12057.700	28.22
Pasture (P)	2,2	11001.845	7.56
Y X P	2	1372.035	2.41
Pasture Period (PP)	4,6	18950.572	5.93*
Y X PP	4	10833.262	6.86*
P X PP	9,11	15075.414	1.45
Y X P X PP	8	9960.650	8.70**
Percent Grain (G)	2,2	5042.556	2.74
Y X G	2	1795.750	4.00
P X G	16,11	852.172	0.98
Y X P X G	4	1230.776	0.99
PP X G	5,8	2745.681	1.88
Y X PP X G	8	1129.470	0.92
P X PP X G	32,13	2828.090	1.52
Y X P X PP X G	15	1611.610	0.56
Rep (R)	2	159.241	0.19
Y X R	2	854.494	13.89**
R X R	4	312.939	0.28
Y X R X R	4	1103.332	8.97**
PP X R	8	1177.337	0.94
Y X PP X R	8	1577.535	6.41**
P X PP X R	16	3101.668	2.71**
Y X P X PP X R	16	1145.018	2.33**
G X R	4	245.568	0.54
Y X G X R	4	448.780	3.65**
P X G X R	8	243.120	0.20
Y X P X G X R	8	1233.066	5.01**
PP X G X R	16	1102.035	1.32
Y X PP X G X R	16	831.210	1.69*
P X PP X G X R	32	2378.968	0.83
Y X P X PP X G X R	32	2873.744	2.92**
Error	1350	41512.457	--

APPENDIX TABLE 21

Analysis of Variance for Van Soest 1973b Method 2 Estimated DMI

Source	Df	SS	F
Total	1619	160132.282	--
Model	269	118514.179	--
Year (Y)	1	9278.056	14.54
Pasture (P)	2,5	14942.109	16.74**
Y X P	2	101.447	0.16
Pasture Period (PP)	4,5	16007.226	1.81
Y X PP	4	8710.910	8.51**
P X PP	9,22	8647.791	1.97
Y X P X PP	8	9891.569	19.62**
Percent Grain (G)	2,6	4330.735	4.02
Y X G	2	537.818	1.65
P X G	11,16	1032.699	1.79
Y X P X G	4	607.173	1.39
PP X G	7,18	4304.377	4.11**
Y X PP X G	8	454.870	1.22
P X PP X G	38,46	3503.246	1.44
Y X P X PP X G	16	1103.640	0.42
Rep (R)	2	505.127	0.40
Y X R	2	1276.050	20.70**
R X R	4	1656.623	6.70
Y X R X R	4	1236.964	10.03**
PP X R	8	1385.497	0.68
Y X PP X R	8	2047.626	8.30**
P X PP X R	16	5168.687	5.12**
Y X P X PP X R	16	1008.367	2.04**
G X R	4	1239.803	1.90
Y X G X R	4	651.274	5.28**
P X G X R	8	1673.932	1.92
Y X P X G X R	8	871.229	3.53**
PP X G X R	16	1884.283	0.66
Y X PP X G X R	16	2868.036	5.81**
P X PP X G X R	32	6313.657	1.19
Y X P X PP X G X R	32	5273.353	5.35**
Error	1350	41618.103	--

APPENDIX TABLE 22

Analysis of Variance for Colburn and Evans 1968 Method 3A
Estimated DMI

Source	Df	SS	F
Total	1619	4454.217	--
Model	269	4087.404	--
Year (Y)	1	70.841	59.13*
Pasture (P)	3,2	16.639	1.93
Y X P	2	10.112	2.59
Pasture Period (PP)	4,4	578.437	319.21**
Y X PP	4	1.731	5.00*
P X PP	10,21	4.721	3.88**
Y X P X PP	8	1.466	3.00*
Percent Grain (G)	2,2	3295.072	235.23**
Y X G	2	13.605	18.34**
P X G	14,15	4.800	4.16**
Y X P X G	4	0.674	0.30
PP X G	8,9	60.751	41.48**
Y X PP X G	8	1.341	9.89**
P X PP X G	33,44	0.966	1.96*
Y X P X PP X G	16	0.356	0.70
Rep (R)	2	0.428	0.18
Y X R	2	2.400	4.41**
P X R	4	1.050	0.14
Y X P X R	4	7.808	7.18**
PP X R	8	0.164	0.24
Y X PP X R	8	0.692	0.32
P X PP X R	16	1.300	1.33
Y X P X PP X R	16	0.978	0.22
G X R	4	0.691	0.46
Y X G X R	4	1.484	1.37
P X G X R	8	2.049	0.45
Y X P X G X R	8	4.514	2.08*
PP X G X R	16	0.254	0.94
Y X PP X G X R	16	0.271	0.06
P X PP X G X R	32	0.792	0.77
Y X P X PP X G X R	32	1.020	0.12
Error	1350	366.813	--

APPENDIX TABLE 23

Analysis of Variance for Colburn and Evans 1968 Method 3B Estimated DMI

Source	Df	SS	F
Total	1619	5278.837	--
Model	269	4666.442	--
Year (Y)	1	119.783	59.93
Pasture (P)	3,5	29.512	7.42*
Y X P	2	17.388	2.64
Pasture Period (PP)	4,8	971.558	224.91**
Y X PP	4	2.862	4.96*
P X PP	10,15	8.001	2.45
Y X P X PP	8	2.529	3.00*
Percent Grain (G)	2,2	3372.885	180.36**
Y X G	2	18.135	16.43*
P X G	14,15	7.568	3.86**
Y X P X G	4	1.159	0.33
PP X G	4,5	68.888	32.61**
Y X PP X G	8	1.917	0.27
P X PP X G	35,44	1.332	1.87*
Y X P X PP X G	16	0.544	0.68
Rep (R)	2	0.660	0.16
Y X R	2	3.997	4.41**
P X R	4	1.743	0.13
Y X P X R	4	13.191	7.27**
PP X R	8	0.292	0.25
Y X PP X R	8	1.153	0.32
P X PP X R	16	2.169	1.29
Y X P X PP X R	16	1.682	0.23
G X R	4	1.144	0.52
Y X G X R	4	2.208	1.22
P X G X R	8	3.446	0.48
Y X P X G X R	8	7.119	1.96*
PP X G X R	16	0.403	1.06
Y X PP X G X R	16	0.381	0.05
P X PP X G X R	32	1.190	0.74
Y X P X PP X G X R	32	1.601	0.11
Error	1350	612.396	--

APPENDIX TABLE 24

Analysis of Variance for Rohweder 1981 Method 4 Estimated DMI

Source	Df	SS	F
Total	1619	5208.017	--
Model	269	4350.156	--
Year (Y)	1	74.615	27.87
Pasture (P)	2,1	313.562	47.58*
Y X P	2	111.906	8.62
Pasture Period (PP)	4,5	82.343	1.81
Y X PP	4	43.897	16.03**
P X PP	9,10	91.278	1.60
Y X P X PP	8	52.817	14.212**
Percent Grain (G)	2,2	3313.075	127.83**
Y X G	2	24.572	53.59*
P X G	16,16	17.041	2.10
Y X P X G	4	5.996	0.81
PP X G	4,7	78.769	21.84**
Y X PP X G	8	2.853	0.86
P X PP X G	17,30	10.055	0.96
Y X P X PP X G	16	7.590	1.99
Rep (R)	2	0.867	0.16
Y X R	2	5.355	4.21**
P X R	4	3.016	0.12
Y X P X R	4	25.970	10.22**
PP X R	8	6.273	1.14
Y X PP X R	8	5.477	1.08
P X PP X R	16	12.875	1.73
Y X P X PP X R	16	7.432	0.73
G X R	4	2.699	2.94
Y X G X R	4	0.917	0.36
P X G X R	8	11.323	0.76
Y X P X G X R	8	14.836	2.92**
PP X G X R	16	1.811	0.27
Y X PP X G X R	16	6.660	0.66
P X PP X G X R	32	6.660	0.87
Y X P X PP X G X R	32	7.614	0.37
Error	1350	857.861	--

APPENDIX TABLE 25

Quasi F's for Methods of Estimating DMI

$$\text{Pasture} = \frac{\text{M.S. P} + \text{M.S. Y X P X R}}{\text{M.S. P X R} + \text{M.S. Y X P}}$$

$$\text{Pasture Period} = \frac{\text{M.S. PP} + \text{M.S. PP X Y X R}}{\text{M.S. PP X R} + \text{M.S. Y X PP}}$$

$$\text{Pasture X Pasture Period} = \frac{\text{M.S. P X PP} + \text{M.S. Y X P X PP X R}}{\text{M.S. P X PP X R} + \text{M.S. Y X P X PP}}$$

$$\text{Percent Grain} = \frac{\text{M.S. G} + \text{M.S. Y X G X R}}{\text{M.S. G X R} + \text{M.S. Y X G}}$$

$$\text{Pasture X Percent Grain} = \frac{\text{M.S. P X G} + \text{M.S. Y X P X G X R}}{\text{M.S. P X G X R} + \text{M.S. Y X G X P}}$$

$$\text{Pasture Period X Percent Grain} = \frac{\text{M.S. PP X G} + \text{M.S. Y X PP X G X R}}{\text{M.S. PP X G X R} + \text{M.S. Y X PP X G}}$$

$$\text{Pasture X Pasture Period X Percent Grain} = \frac{\text{M.S. P X PP X G} + \text{M.S. Y X P X PP X G X R}}{\text{M.S. P X PP X R} + \text{M.S. Y X P X PP X G}}$$

Documentation:

Y = Year
P = Pasture
PP = Pasture Period
G = Percent Grain
R = Rep

APPENDIX TABLE 26

Degrees of Freedom for Methods of Estimating DMI

$$\text{Pasture} = \frac{\dfrac{(\text{M.S. P} + \text{M.S. Y X P X R})^2}{\dfrac{(\text{M.S. P})^2}{\text{P df}} + \dfrac{(\text{M.S. Y X P X R})^2}{\text{Y X P X R df}}}}{\dfrac{(\text{M.S. P X R} + \text{M.S. Y X P})^2}{\dfrac{(\text{M.S. P X R})^2}{\text{P X R df}} + \dfrac{(\text{M.S. Y X P})^2}{\text{Y X P df}}}}$$

$$\text{Pasture Period} = \frac{\dfrac{(\text{M.S. PP} + \text{M.S. PP X Y X R})^2}{\dfrac{(\text{M.S. PP})^2}{\text{PP df}} + \dfrac{(\text{M.S. PP X Y X R})^2}{\text{PP X Y X R df}}}}{\dfrac{(\text{M.S. PP X R} + \text{M.S. Y X PP})^2}{\dfrac{(\text{M.S. PP X R})^2}{\text{PP X R df}} + \dfrac{(\text{M.S. Y X PP})^2}{\text{Y X PP df}}}}$$

$$\text{Pasture X Pasture Period} \quad \frac{\dfrac{(\text{M.S. P X PP} + \text{M.S. Y X P X PP X R})^2}{\dfrac{(\text{M.S. P X PP})^2}{\text{P X PP df}} + \dfrac{(\text{M.S. Y X P X PP X R})^2}{\text{Y X P X PP X R df}}}}{\dfrac{(\text{M.S. P X PP X R} + \text{M.S. Y X P X PP})^2}{\dfrac{(\text{M.S. P X PP X R})^2}{\text{P X PP X R df}} + \dfrac{(\text{M.S. Y X P X PP})^2}{\text{Y X P X PP df}}}}$$

$$\text{Percent Grain} = \frac{\dfrac{(\text{M.S. G} + \text{M.S. Y X G X R})^2}{\dfrac{(\text{M.S. G})^2}{\text{G df}} + \dfrac{(\text{M.S. Y X G X R})^2}{\text{Y X G X R df}}}}{\dfrac{(\text{M.S. G X R} + \text{M.S. Y X G})^2}{\dfrac{(\text{M.S. G X R})^2}{\text{G X R df}} + \dfrac{(\text{M.S. Y X G})^2}{\text{Y X G df}}}}$$

APPENDIX TABLE 26 CONTINUED

$$\text{Pasture X Percent Grain} = \frac{\dfrac{(\text{M.S. P X G} + \text{M.S. Y X P X G X R})^2}{\dfrac{(\text{M.S. P X G})^2}{\text{P X G df}} + \dfrac{(\text{M.S. Y X P X G X R})^2}{\text{Y X P X G X R df}}}}{\dfrac{(\text{M.S. P X G X R} + \text{M.S. Y X G X P})^2}{\dfrac{(\text{M.S. P X G X R})^2}{\text{P X G X R df}} + \dfrac{(\text{M.S. Y X G X P})^2}{\text{Y X G X P df}}}}$$

$$\text{Pasture Period X Percent Grain} = \frac{\dfrac{(\text{M.S. PP X G} + \text{M.S. Y X PP X G X R})^2}{\dfrac{(\text{M.S. PP X G})^2}{\text{PP X G df}} + \dfrac{(\text{M.S. Y X PP X G X R})^2}{\text{Y X PP X G X R df}}}}{\dfrac{(\text{M.S. PP X G X R} + \text{M. S. Y X PP X G})^2}{\dfrac{(\text{M.S. PP X G X R})^2}{\text{PP G X R df}} + \dfrac{(\text{M.S. Y X PP X G})^2}{\text{Y X PP X G df}}}}$$

$$\text{Pasture X Pasture Period X Percent Grain} = \frac{\dfrac{(\text{M.S. P X PP X G} + \text{M.S. Y X P X PP X G X R})^2}{\dfrac{(\text{M.S. P X PP X G})^2}{\text{P X PP X G df}} + \dfrac{(\text{M.S. Y X P X PP X G X R})^2}{\text{Y X P X PP X G X R df}}}}{\dfrac{(\text{M.S. P X PP X R} + \text{M.S. Y X P X PP X G})^2}{\dfrac{(\text{M.S. P X PP X R})^2}{\text{P X PP X R df}} + \dfrac{(\text{M.S. Y X P X PP X G})^2}{\text{Y X P X PP X G df}}}}$$

Documentation:

Y = Year
P = Pasture
PP = Pasture Period
G = Percent Grain
R = Rep

APPENDIX TABLE 27

Analysis of Variance for ADG of grazing steers

Source	Df	SS	F
Total	485	74.369	--
Year (Y)	2	34.164	127.56**
Pasture (P)	58,5	0.483	1.03
Y X P	4	1.333	2.488*
Rep [(P)]	6	0.183	0.23
Y X Rep [(P)]	12	1.607	2.59**
Grain (G)	2,5	9.262	6.98*
Y X G	4	2.410	9.847**
P X G	9,15	0.467	0.78
Y X P X G	8	1.256	2.56*
G X Rep [(P)]	12	0.841	1.14
Y X G X Rep [(P)]	24	1.468	1.18
Animal (Y P G Rep)	405	20.896	--

APPENDIX TABLE 28

Analysis of Variance for Animal Gains per Ha

Source	Df	SS	F
Total	80	43416.652	--
Year (Y)	2	6843.725	34.47**
Pasture (P)	1,4	17447.094	12.38*
Y X P	4	2786.768	7.02**
Rep [(P)]	6	93.111	0.16
Y X Rep [(P)]	12	1191.355	3.20*
Grain (G)	2,10	12407.939	36.53**
Y X G	4	396.707	3.19*
P X G	7,19	390.457	1.24
Y X P X G	8	257.112	1.03
G X Rep [(P)]	12	858.202	2.03*
Y X G X Rep [(P)]	24	744.181	--

[ ] Means "nested in"

APPENDIX TABLE 29

Analysis of Variance for AUM/ha

Source	Df	SS	F
Total	80	6.010	--
Year (Y)	2	0.498	59.64**
Pasture (P)	2,5	3.714	13.01*
Y X P	4	0.518	31.02**
Rep [(P)]	6	0.081	3.24*
Y X Rep [(P)]	12	0.050	1.35
Grain (G)	2,5	0.739	7.95*
Y X G	4	0.165	13.39**
P X G	5,19	0.086	3.18*
Y X P X G	8	0.017	0.71
G X Rep [(P)]	12	0.066	1.78
Y X G X Rep [(P)]	24	0.074	--

[ ] Means "nested in"

APPENDIX TABLE 30

Quasi F's for Animal Performance Data

$$\text{Pasture} = \frac{\text{M.S. P} + \text{M.S. Y X R [P]}}{\text{M.S. R [P]} + \text{M.S. Y X R}}$$

$$\text{Percent Grain} = \frac{\text{M.S. G} + \text{M.S. Y X G X R [P]}}{\text{M.S. Y X G} + \text{M.S. G X R [P]}}$$

$$\text{Pasture X Percent Grain} = \frac{\text{M.S. P X G} + \text{M.S. Y X G X R [P]}}{\text{M.S. Y X P X G} + \text{M.S. G X R [P]}}$$

Documentation:

Y = Year
P = Pasture
G = Percent Grain
R = Rep
[ ] = nested within

APPENDIX TABLE 31

Degrees of Freedom for Animal Performance Data

$$\text{Pasture} = \frac{\dfrac{(\text{M.S. P} + \text{M.S. Y X R [P]})^2}{\dfrac{(\text{M.S. P})^2}{\text{P df}} + \dfrac{(\text{M.S. Y X R [P]})^2}{\text{Y X R [P] df}}}}{\dfrac{(\text{M.S. R [P]} + \text{M.S. Y X P})^2}{\dfrac{(\text{M.S. R [P]})^2}{\text{R [P] df}} + \dfrac{(\text{M.S. Y X P})^2}{\text{Y X P df}}}}$$

$$\text{Percent Grain} = \frac{\dfrac{(\text{M.S. G} + \text{M.S. Y X G X R [P]})^2}{\dfrac{(\text{M.S. G})^2}{\text{G df}} + \dfrac{(\text{M.S. Y X G X R [P]})^2}{\text{Y X G X R [P] df}}}}{\dfrac{(\text{M.S. Y X G} + \text{M.S. G X R [P]})^2}{\dfrac{(\text{M.S. Y X G})^2}{\text{Y X G df}} + \dfrac{(\text{M.S. G X R [P]})^2}{\text{G X R [P] df}}}}$$

$$\text{Pasture X Percent Grain} = \frac{\dfrac{(\text{M.S. P X G} + \text{M.S. Y X G X R [P]})^2}{\dfrac{(\text{M.S. P X G})^2}{\text{P X G df}} + \dfrac{(\text{M.S. Y X G X R [P]})^2}{\text{Y X G X R [P] df}}}}{\dfrac{(\text{M.S. Y X P X G} + \text{M.S. G X R [P]})^2}{\dfrac{(\text{M.S. Y X P X G})^2}{\text{Y X P X G df}} + \dfrac{(\text{M.S. G X R [P]})^2}{\text{G X R [P] df}}}}$$

Documentation:

Y = Year
P = Pasture
G = Percent Grain
R = Rep
[ ] = nested within
df = degrees of freedom

APPENDIX TABLE 32

Example of Estimating Mean Average Daily Gain For Equation 2, Van Soest 1973b DMI X IVDMD

Equation 2:

Mean average daily gain for a group of steers on pasture = $-0.344 - 0.00338 \times EDFI - 0.000057 \times EDFI^2 + 1.93 \times 10^{-7} \times EDFI^3 + 0.0541 \times RFV - 0.000208 \times RFV^2 - 0.096 \times NDF + 0.000979 \times NDF^2 + 0.044 \times GNE$.

Data Input:

IVDMD = 60.00	Estimated body wt. = 200 kg
NDF = 50.00	Pasture Period = 1
RFV = 115.00	

MADG @ 0.0 grain level = 0.869 kg/day
MADG @ 0.5 grain level = 0.913 kg/day
MADG @ 1.0 grain level = 0.957 kg/day